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Simulation of Changes in Stormwater Quality at Four Potential Flow-Attenuation Sites in the Irondequoit Creek Watershed, Monroe County, New York

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CONVERSION FACTORS AND ABBREVIATIONS

The following factors may be used to convert the inch-pound units used in this report to metric (International System) units.

Multiply Inch-Pound Unit	By	To Obtain Metric Units
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
pound (lb)	0.4536	kilogram (kg)
ton (short)	907.2	kilogram (kg)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.59	square kilometer (km^2)
acre	0.4047	square kilometer (km^2)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
gallon per day (gal/d)	3.785	liter per day (L/d)
million gallons per day (Mgal/d)	43.81	liter per second (L/s)
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)
foot per day (ft/d)	0.3048	meter per day (m/d)
foot squared per day (ft^2/d)	0.09290	meter squared per day (m^2/d)
cubic foot per second per square mile [$(ft^3/s)/mi^2$]	0.01903	cubic meters per second per square kilometer [$(m^3/s)/km^2$]
parts per million	1.0	milligrams per liter (mg/L)
parts per billion	1.0	micrograms per liter (mg/L)
pound per cubic foot (lb/ft^3)	16.02	kilograms per cubic meter (kg/m^3)

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)--a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "sea level datum of 1929."

SIMULATION OF CHANGES IN STORMWATER QUALITY AT FOUR POTENTIAL FLOW-ATTENUATION SITES IN THE IRONDEQUOIT CREEK WATERSHED, MONROE COUNTY, NEW YORK

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Abstract

Flow-attenuation basins have been proposed as a management practice for controlling nonpoint-source runoff, which is a major source of sediment and adsorbed chemical constituents that enter Irondequoit Bay through Irondequoit Creek. The degree to which water-quality improvements in the bay can be achieved through use of such basins depends on how much water is retained in the basin and for how long, and on the discharge and water-quality characteristics of stormflow.

A deterministic model was used to predict sediment-load retention during three or four moderate to large stormflows at each of four sites in the Irondequoit Creek watershed. Two basin designs were simulated for each site--a temporary-storage basin, which retains storm runoff but allows normal runoff to pass unimpeded, and a maximum-storage basin, which maintains a permanent pool of water.

The predicted outflow hydrographs from the basins differ little from the inflow hydrographs because each basin's storage capacity is small in relation to its contributing drainage area. The attenuation of peak flows in all simulations ranged from 0 to 46 percent and varied with control design, inflow, and storage capacity. Retention time was greater in maximum-storage basins than in temporary-storage basins in moderate stormflows, but this difference was minimal in the simulation of the large February 1981 stormflow.

The predicted decrease in suspended-sediment load varied with particle-size distribution and detention time, both of which are a function of basin size and rate of inflow. The predicted annual decrease in suspended-sediment load, based on the mean particle-size distribution, ranged from 28 to 32 percent in temporary-storage basins and from 33 to 60 percent in maximum storage basins. This range varied according to the proportion of clay to sand: within the observed particle-size distribution range, a high proportion of clay-size particles decreased the retention efficiency by 20 to 30 percent, whereas a high proportion of sand-size particles increased it by 20 to 30 percent. The greater detention time provided by maximum-storage basins produced an 8- to 84-percent greater decreae in suspended-sediment load than temporary-storage basins. The predicted rate of sediment accumulation within the basins would cause maximum-storage basins to fill with sediment approximately twice as fast as temporary-storage basins.

Calculations based on results of the simulations indicate that the flow-attenuation basins would decrease total annual phosphorus loads by 22 to 59 percent, lead loads by 20 to 47 percent, and zinc loads by 16 to 38 percent. The maximum-storage basins would retain between 30 and 100 percent more of the particulate phase of these constituents than the temporary-storage basins

because they provide greater sediment retention. Actual water-quality improvement may be less than predicted, however, because (1) the sediments may be resuspended mechanically, (2) anaerobic conditions may cause release of constituents into the dissolved phase, and (3) metals may remobilize in the presence of elevated concentrations of chloride from road salt.

The effects of flow-attenuation basins on loads entering Irondequoit Bay will depend on the number and design of basins used, stormflow characteristics, and several other factors. The performance of flow-attenuation basins may be diminished by upstream basins, which would increase the proportion of clay-size sediments and thereby decrease the trap efficiency of downstream basins. Flow-attenuation basins also may cause changes in streambed morphology by decreasing the sediment load in basin outflow, which can increase erosion downstream. As a result, the addition of basins above the site furthest downstream (Blossom site) may increase the removal of suspended sediment and associated chemical constituents only moderately. To date (1988), effects of flow-attenuation basins are not well documented, and field tests would be needed to confirm the model predictions.

INTRODUCTION

Irondequoit Bay was a principal recreational resource for the adjacent city of Rochester, N.Y., and surrounding communities until sewage and other contaminants began to dimnish its water quality as early as the late 1800's. By the late 1970's, the bay was characterized as a sewage-oxidation pond that supported an immense growth of aquatic vegetation; also it was depleted of dissolved oxygen needed by fish and other aquatic organisms and, in general, was considered a potential health hazard (Bannister and Bubeck, 1978). This advanced eutrophic condition of the bay, together with the countywide deterioration of streams, aroused public concern that led to the creation of the Monroe County Pure Water Agency (MCPWA), whose charge was to improve county waste-treatment facilities, a primary source of contaminants to stream and to the bay. The MCPWA directed millions of dollars of local public support and grants provided by Public Law 92-500 and the Clean Water Act Amendments (Public Law 92-217) toward the construction of a modern waste-treatment facility and an interceptor network to eliminate discharge of combined sewer overflows and poorly treated sewage from several small treatment facilities to the bay and its tributaries. Although these efforts sharply decreased the inflow of phosphorus and other constituents to the bay, the improvement in the eutrophic status of the bay was less than desired (O'Brien and Gere, 1983).

As point-source discharges of contaminants were reduced or eliminated, contaminants derived from nonpoint sources, particularly urbanized areas, were found to be adversely affecting water quality at least as much as the contaminants from point sources (Whipple and others, 1974; Wildrick and others, 1976). This problem was recognized locally, and programs were developed to assess effects of nonpoint runoff from urban and agricultural areas and internal cycling of nutrients and other contaminants in the bay.

The National Urban Runoff Program (NURP), administered through the U.S. Environmental Protection Agency (USEPA), began in the 1970's to examine the effect of urban storm runoff on stream-water quality and to evaluate management strategies for controlling the migration of contaminants in urban runoff (U.S. Environmental Protection Agency, 1983). The Irondequoit Creek basin was studied during 1980-81 as part of the NURP program because much of it is highly urbanized and because steps taken previously to improve the chemical quality of Irondequoit Bay did not completely achieve the desired objectives. Results of the Irondequoit NURP study (Kappel and others, 1986) indicated that 20 tons of phosphorus, 19,000 tons of suspended solids, 214 tons of Kjeldahl nitrogen, 2,500 tons of chemical oxygen demand, 16,000 tons of dissolved chloride, 3.5 tons of lead, 88 tons of zinc, and 1.4 tons of cadmium were transported into Irondequoit Bay from August 1980 through August 1981 from the Irondequoit Creek watershed. These findings showed that constituents from nonpoint sources are major contributors to eutrophic conditions in the bay and need to be limited to improve water quality in the bay.

One of the more promising strategies for managing nonpoint-source runoff is the use of flow-attenuation basins (U.S. Environmental Protection Agency, 1983). Several sites in the Irondequoit basin have been identified as possible locations for such basins (O'Brien and Gere, 1983), which provide storage for some initial volume of stormflow and allow some of the suspended material to settle. As urban areas expand, the capacity of a watershed for infiltration and storage of water decreases, and channelization and decreases in surface roughness accelerate the movement of stormwater on the surface (Hawley and others, 1982; VenHaveren, 1986). These factors affect both runoff and the entrainment of sediment and its associated chemical constituents (Yorke and Herb, 1978; and Miller, 1985). Flow-attenuation basins generally decrease the velocity of stormflow and thereby allow suspended sediment and associated constituents to settle and accumulate within the basin. Biochemical activity may also occur within such basins, which enhances the assimilative capacity of the stream (Hey and Schaefer, 1983).

The performance of a basin will depend on fixed characteristics such as storage capacity and outlet design, as well as variable characteristics such as stormflow volume and the relation between dissolved and particulate constituents and particle-size distribution. To obtain information on how these variables influence basin performance, the U.S. Geological Survey, in cooperation with the Monroe County Department of Engineering, began a study in 1984 to simulate the effect of flow-attenuation basins on stormflow and water quality at four selected locations in the Irondequoit Creek watershed. The simulations were derived from a water-quality model developed and used for the NURP program (Kappel and others, 1986) and from the data collected during that study, July 1980 through August 1981 (Zarriello and others, 1985).

Purpose and Scope

This report describes results of simulated stormflow attenuation and suspended-sediment deposition in temporary-storage basins, which impound water during high flows, and maximum-storage basins, which maintain a permanent pool of water. It also examines (1) the effect of particle-size distribution and bedload transport on sediment deposition in both types of basins; (2) the relation of suspended-sediment loads to adsorbed phosphorus, lead, and zinc loads, and (3) the overall effect that the use of these basins could have on the transport of suspended constituents to Irondequoit Bay.

Maps and sketches depict the location and physical characteristics of the selected sites; hydrographs present the flow characteristics of selected storms; and tables and graphs present data on simulated discharge and sedimentation, trap efficiency, and estimated decrease in load for each type of basin at each site.

Acknowledgments

This study was done in cooperation with the Monroe County Department of Engineering. The authors extend special thanks to Richard Burton of the Monroe County Environmental Health Laboratory and Margaret Peet of the Monroe County Department of Planning for their suggestions throughout the study.

SITE DESCRIPTIONS

Six sites were identified as possible locations for flow-attenuation basins (O'Brien and Gere, 1983), four of which were selected for simulation because they were at or near sites where streamflow and water-quality data collected during 1980-81 were available (fig. 1). Although O'Brien and Gere (1983) considered two of the four sites (Blossom and Linden) unsuitable, they were included in this study because the Blossom site would be the simplest to implement if the land could be acquired, and the Linden site, despite its limited storage capacity, may have adequate potential to improve water quality.

Three of the sites (Thornell, Linden, and Blossom, fig. 1) lie in succession along Irondequoit Creek; the fourth (Allen) is on Allen Creek near its junction with Irondequoit Creek. Site descriptions are given below in downstream order.

Thornell Site

The control at the Thornell site would be in a channel constriction in Irondequoit Creek just south of State Highway Route 96 and the Erie-Barge Canal (fig. 1). Discharge and water-quality data used for this analysis were colledted 2.4 mi (miles) upstream at the Thornell Road gage (04232040). The drainage area above the gaging station is 44.4 mi^2 (square miles) and contains mostly agricultural, rural, and undeveloped land (Kappel and others, 1986). Inclusion of the control adds an additional 8.1 mi^2 of similar land use. Discharge measured at the Thornell gage was multiplied by 1.18 to account for this 18-percent increase in drainage area. Surficial deposits underlying the basin area are moderately permeable, fine lake sand and recent alluvium (Yager and others, 1985).

Current land use would allow a maximum pool elevation of about 410 ft above sea level. Some residential properties may be flooded at this elevation, but a large, low-lying area between the control and Thornell Road (fig. 9A, p. 26) could be used for storage. The storage capacity at this elevation is equal to about 0.28 in. of runoff or about 5.44 in. of rain as calculated from the log-transformed mean-runoff coefficient of stormflows measured during the NURP study (Zarriello and others, 1985). The potential storage capacity and pool-surface area for a range of pool-surface elevations of this site are plotted in figure 2A (p. 6).

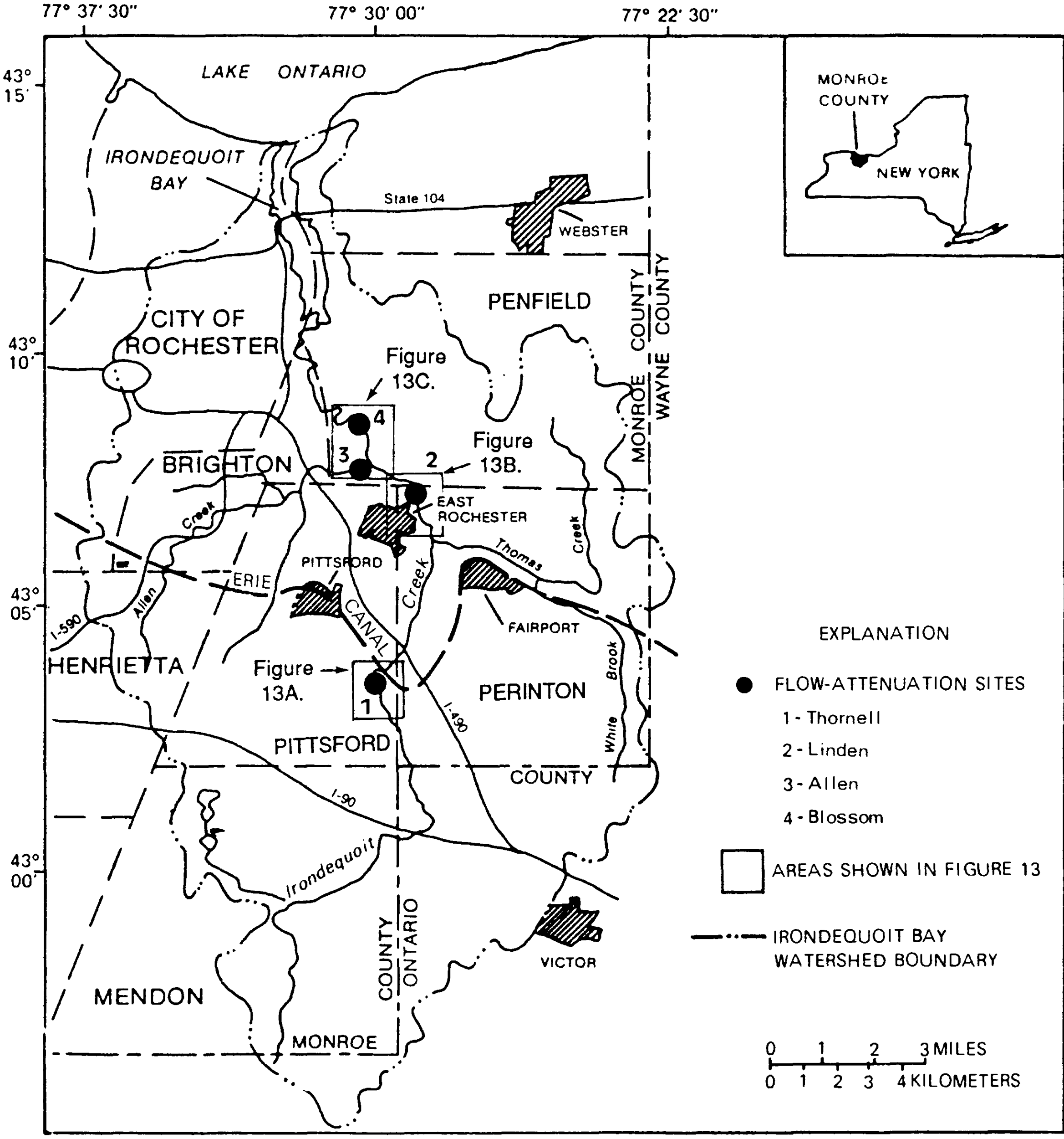

Figure 1.--Principal geographic features of Irondequoit Creek basin and locations of simulated flow-attenuation basins.

Linden Site

The Linden site (04232047) is 5.4 mi downstream from the Thornell site (fig. 1). It is the location of a former mill dam and is one of the sites where discharge and water-quality data were collected during the NURP study (fig. 9B, p. 27). The intervening 47.5-mi^2 drainage area is more densely populated and commercially developed than the Thornell drainage (Kappel and others, 1986). Total drainage area above the Linden site is 101 mi^2. Surficial deposits underlying the valley in the area of the simulated flow-attenuation basin also are moderately permeable, fine lake sand and recent alluvium (Yager and others, 1985).

The maximum pool elevation allowed for the basin simulation (about 370 ft above sea level) would encroach on town maintenance and park facilities. The storage capacity at this elevation is equal to about 0.09 in. of runoff, or about 1 in. of rain, as calculated from storms measured during the NURP study. The U.S. Army Corps of Engineers flood-control report (1982) and the NURP study (O'Brien and Gere, 1983) considered the storage capacity at this site inadequate for downstream flood protection. The potential storage capacity and pool surface area over a range of pool elevations are plotted in figure 2B.

Allen Site

The Allen site would be in a channel constriction on Allen Creek 0.19 mi upstream from its confluence with Irondequoit Creek (fig. 1). Of the major Irondequoit Creek subbasins, this is the most highly developed and contributes

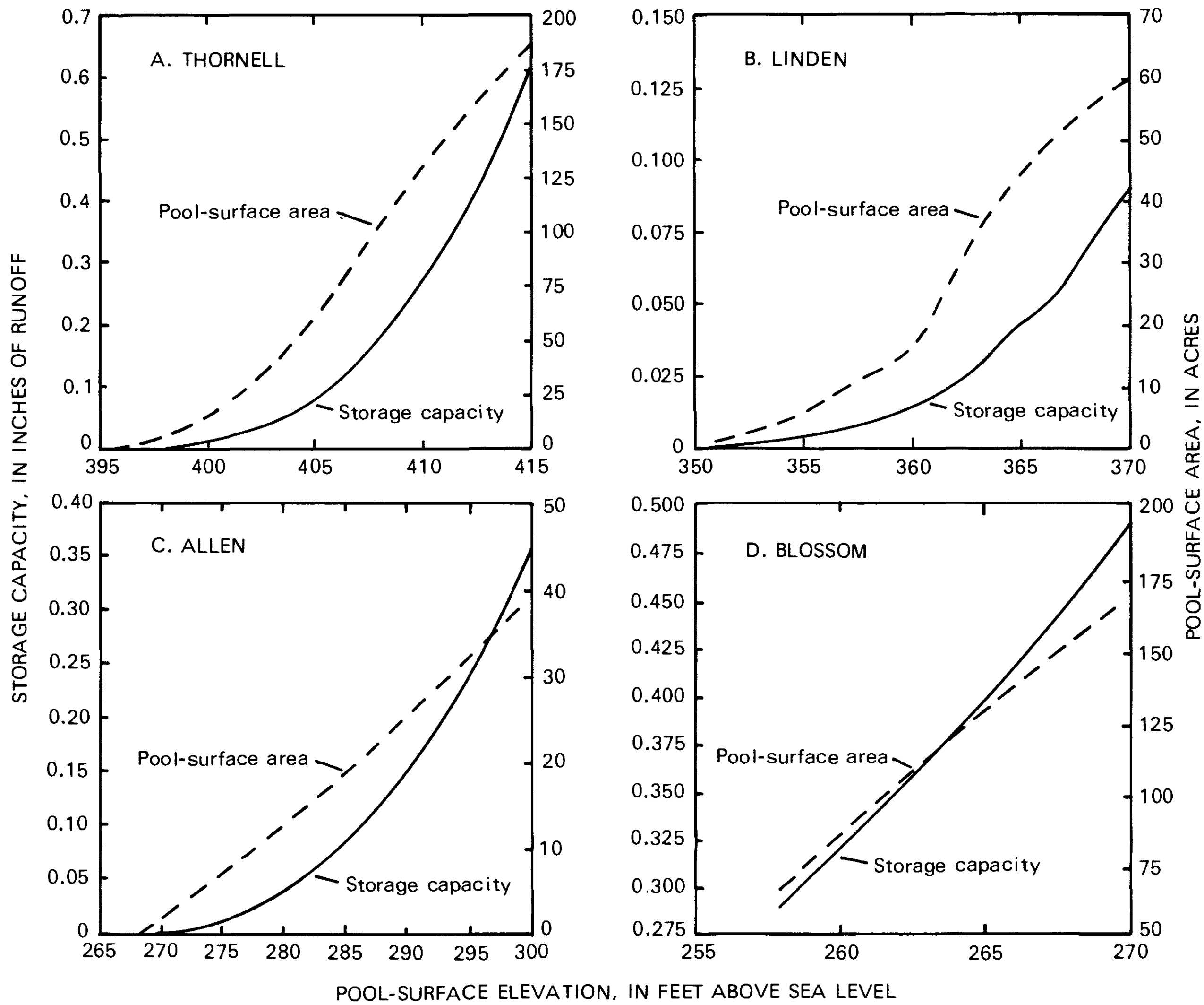

Figure 2.--Relations among pool-surface elevation, storage capacity, and pool-surface area.

the highest chemical loads per unit area (Kappel and others, 1986). Data were collected during the NURP study at the Allen Creek gage (04232050), 1.2 mi upstream of the site (fig. 9C, p. 28). The drainage area above the gaging station is 30.1 mi^2. No flow adjustments were made for the 0.60 mi^2 of drainage area between the site and the gaging station. Moderately permeable lake silt and fine sand underlies the area of the flow-attenuation basin (Yager and others, 1985).

The stream channel is much narrower and the channel banks much steeper here than at the other sites, and the pool elevation would be limited by control-structure height rather than by land-use constraints. The potential pool-storage capacity and surface area over a range of pool-surface elevations are plotted in figure 2C. At a surface elevation of 300 ft, storage is equal to about 0.36 in. of runoff, or about 3.04 in. of rain as determined from stormflows measured during the NURP study.

Blossom Site

The Blossom site (fig. 1) is just upstream of Blossom Road (fig. 9C, p. 28), where streamflow and water-quality data were collected during the NURP study. The drainage area above the gaging station (0423205010) is 143 mi^2, which includes an additional 11.9 mi^2 of moderately developed area downstream of the Allen and Linden sites. The surficial deposits are moderately permeable alluvial materials overlain by more permeable sand and gravel (Yager and others, 1985).

An active gravel quarry lies 0.40 mi upstream from the Blossom Road gaging station. If the quarry were made available, Irondequoit Creek could be directed into it to form a flow-attenuation basin; this was one of the configurations used in the simulations. Also, a control structure was simulated at a channel constriction 0.20 mi upstream from the Blossom Road gaging station (fig. 9C, p. 28). This configuration would inundate the quarry and increase the storage capacity and surface area of the control pool, as indicated in figure 2D.

Flooding at a shopping plaza approximately 1 mi upstream of the gaging site (fig. 9C) would require a maximum pool elevation of not more than 265 ft above sea level. Storage capacity at this elevation would be equal to about 0.38 in. of runoff or about 4.42 in. of rainfall, according to data from storms measured during the NURP study. The quarry alone has a storage capacity of about 0.29 in. of runoff or about 3.44 in. of rain.

METHODS OF STUDY

Basin Simulation

The simulation of flow-attenuation basins consisted of two parts--a flow model and a sedimentation model. The flow model uses measured streamflow data as inflow to the basin and generates an outflow hydrograph according to the configuration of the basin and its outlet. The sedimentation model then uses the inflow and simulated outflow data with the suspended-sediment concentration and particle-size distribution in the inflow to predict concentrations of suspended sediment in the outflow. The trap efficiency of the basin, expressed as a percentage, is calculated as unity minus the ratio of sediment load out to sediment load in.

Flow Model

The basin-outflow hydrograph was generated from the reservoir routing program developed by Jennings (1977) and based on the modified-Puls method developed by the U.S. Soil Conservation Service (1972). The method applies only to uncontrolled basins and uses the unique storage-to-outflow relations at the control to synthesize the outflow hydrograph from inflow data.

Outflow simulations were made from initial known quantities of inflow, basin storage, and outflow, and were updated for each time step within the model according to the storage-to-outflow relation of the basin. A 15-minute time step was used for the Thornell and Linden sites, and a 60-minute time step was used for the Allen and Blossom sites. A sufficient number of time steps were used to route at least 90 percent of the stormflow through the basin.

The method used to synthesize the outlet hydrograph from a basin does not account for evapotranspiration, changes in bank storage, or changes in groundwater storage. The gains or losses from these sources are likely to be insignificant in relation to the volume of runoff during a storm, thus, the outflow hydrographs are considered reasonably valid for the specified basin designs.

The storage-to-outflow relations differed among the basins, depending mainly on the type of control structure. The temporary-storage type of basin (fig. 3A) was designed to pass low flows unimpeded but to cause ponding during high flows; the maximum-storage type of basin (fig. 3B) was designed with a fixed spillway elevation to maintain a permanent pool. The temporary-storage basin was not simulated for the Blossom site; rather, streamflow would simply be diverted into the nearby quarry. The general configuration of the two control designs is illustrated in figure 3 and described in the following paragraphs. Dimensions of the control geometry, and therefore the storage-to-outflow relations, differed from site to site.

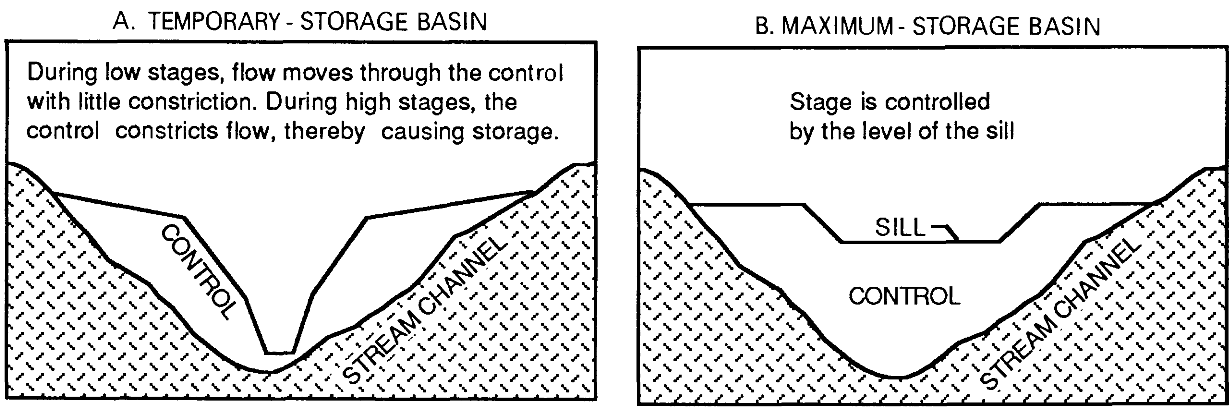

Figure 3.--Front view of typical control configuration for simulation of temporary- and maximum-storage basins.

Temporary-storage basins.--The design of the temporary-storage controls was based on flow-duration analysis of streamflow in accordance with the following criteria:

1. Base flow with a 90-percent flow duration (based on flow-duration curves for the respective sites) should be conveyed through the control and would cause less than a 1-ft rise in stage above the present stream channel,

2. Moderate discharges (with a flow duration between 90 and 50 percent) would cause a rise in stage of 1.0 to 5.0 ft above the stream channel;

3. The highest daily mean flow observed during the period of record would cause a rise in stage of no more than 10 ft above the stream channel, and

4. The instantaneous peak discharge observed during the period of record would not produce a rise above the maximum desirable pool elevation.

The values used for the design criteria of the three temporary-storage basins are summarized in table 1.

A step-backwater analysis (Shearman, 1976) was used to develop the stage-vs-discharge relations for the temporary-storage controls. Assuming critical flow at the control, water level elevations at the approach to the control were calculated for a range of discharges. The control geometry was varied to obtain a match between the upstream approach elevations and the design criteria.

Table 1.--Design discharges for the hydraulic control used in temporary-storage basins.

[Site locations are shown in fig. 1. Discharge values are in cubic feet per second.]

Site	Flow duration		Peak discharge		
	90 percent	50 percent	Daily	Instantaneous	Years of record
Thornell	16	30	410	1,140	3
Linden	35	67	1,100	1,480	10
Allen	8.4	24	1,900	3,280	23

Maximum-storage basins.--The stage-to-discharge relation for the outlet control of the maximum-storage basin design was based on the modified broad-crested weir design described by Hulsing (1967). A control configuration that maximizes discharge for a given range of stages was selected. The width and height of the control for each site were such that simulated historical peak instantaneous flows could be discharged without causing the pool to exceed the desired maximum elevation. The stage-to-discharge relations for each site for both temporary- and maximum-storage controls at each site are plotted in figure 4.

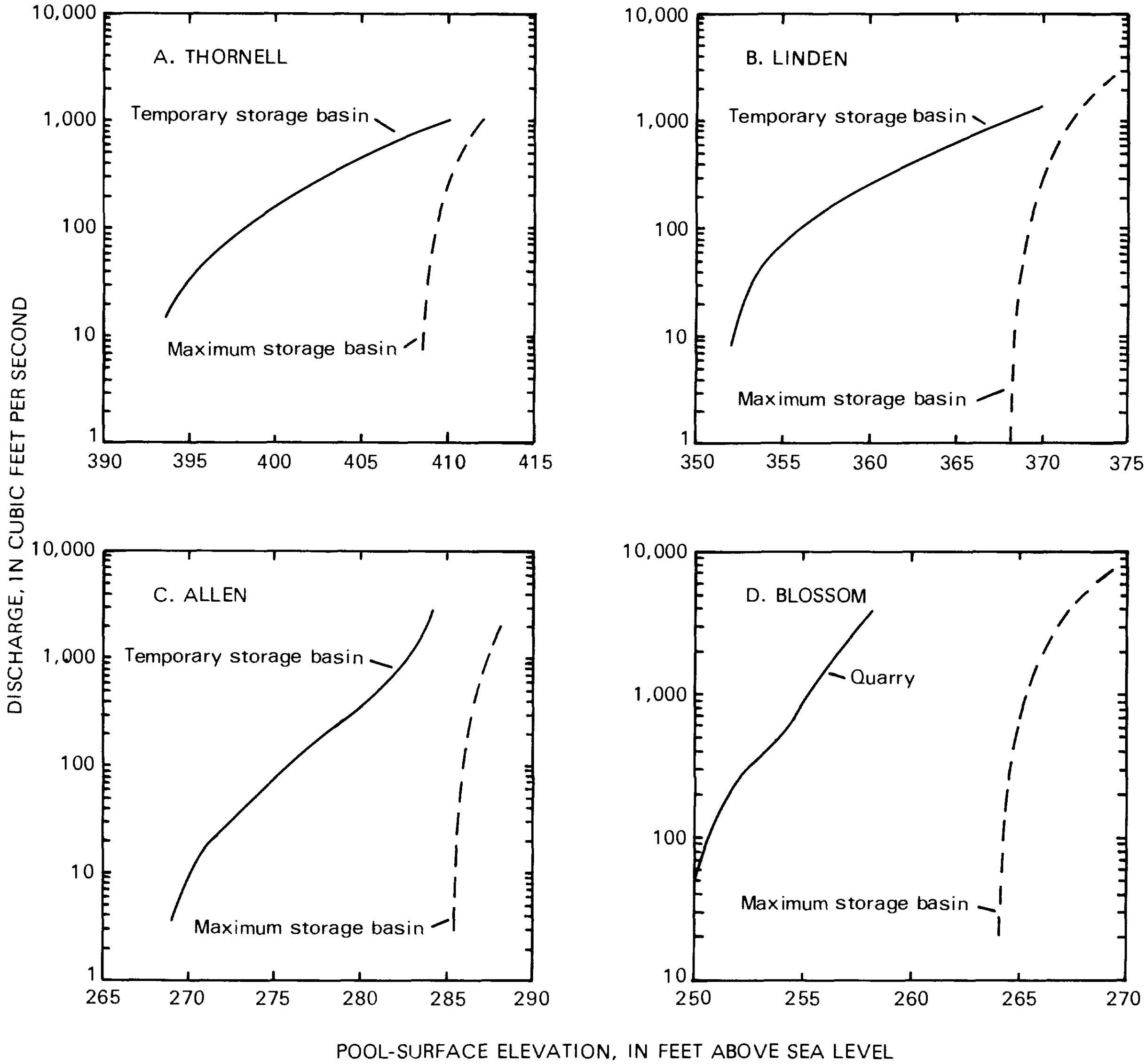

Figure 4.--Stage-vs-discharge relations for simulated temporary- and maximum-storage basins at each site. (Site locations are shown in fig. 1.)

Maximum pool elevation.--Maximum pool elevations calculated for peak discharges with a 100-year recurrence interval for temporary-storage and permanent-storage were 410.3 and 412 ft, respectively, at the Thornell site, 370.3 and 372.8 ft at the Linden site, 284.6 and 289.2 ft at the Allen site, and 257.2 and 267.8 ft at the quarry at the Blossom site. These elevations were based on the historical peak discharge reported for each site (U.S. Geological Survey, 1984). The extreme discharge at Allen Creek, 3,250 ft^3/s, has an expected recurrence interval of about 100 years (Zembrzuski and Dunn, 1979). The peak discharge at Linden was recorded during the same storm, and the peak discharge for Blossom was estimated from the peaks at Linden and Allen during this storm. The peak discharge at Thornell was 80 percent of the peak at Linden.

Storage capacity.--Basin-storage capacity was determined by the trapezoidal method of Alley and Smith (1982) by planimetering contours on enlarged U.S. Geological Survey 7.5-minute topographic maps. The average area between contours multiplied by the contour interval is equal to the volume between the contours. The stage-vs-volume curves in figure 2 indicate the number of inches of runoff from the bed elevation to the maximum desired pool elevation at each site.

Sedimentation Model

The transport and deposition rates of suspended sediment were obtained from the detention-storage part of the Multi-Event Urban Runoff Quality Model (DR_3M-QUAL) developed by Alley and Smith (1982). Particle entrapment is based on the "plug-flow" concept, in which discrete volumes or "plugs" of water are routed through a basin, and the settling of particulate matter within the plug is calculated according to Stoke's Law. The model calculates the time required to route a plug of water through a basin (detention time) in relation to the time required for particles of a given size to settle through the average depth of that plug. Particles that settle to the basin bottom within the time required for the plug to move through the basin are considered trapped.

The detention time of the plug is calculated from the relation between the synthesized outflow hydrograph and the inflow hydrograph. The time lag between the centroids of the cumulative inflow and an equal volume of cumulative outflow at the beginning and end of each time step is equal to the detention time of the plug of water associated with that time step. The geometry of the basin is used with the water stage at the centroids of the inflow plug and the corresponding outflow plug to calculate the average depth of the plug through which particles must fall.

Particulate matter in the plug of water is assumed to settle according to Stoke's Law, which the sedimentation model uses to calculate the particle-settling velocity as a function of the square of the particle diameter. The constant within the function is related to the specific gravity of the particle, the viscosity of the fluid, and an adjustment for the nonspherical shape of particles. All particles falling through the average depth of the plug within the detention time are assumed to be retained. Because particle sizes vary, and because the size largely governs particulate settling rate, the model accounts for the cumulative frequency distribution of up to 10 particle sizes. The particle-size distribution used in the simulations is discussed further on in the section on sediment characteristics.

A basin's trap efficiency is expressed as a percentage and represents unity minus the ratio of sediment loads calculated from the predicted outflow concentration to the loads calculated from the inflow concentration. The accuracy of the trap efficiency predictions is uncertain because many simplifications and assumptions must be made for the simulation of the complex and variable sediment-transport mechanisms. The major assumptions related to flow in a basin are that (1) water flows in discrete plugs from a single inflow at one end of the basin to a single outflow at the opposite end; (2) flow within the plug is laminar; and (3) no mixing occurs between plugs. The model does not account for resuspension or movement of settled particles along the bed, changes in particle-size distribution during a stormflow, or chemical reactions that would remobilize constituents into a dissolved phase.

Phosphorous, Lead, and Zinc Retention

The detention-storage part of the DR_3M-QUAL model can also be used to predict the entrapment of chemical constituents from the transport and deposition of suspended particles. Because the model does not account for chemical reactions that might occur and bases chemical-load retention on the retention of suspended particulate matter, the retention of chemical loads was estimated from sediment retention predicted by the model and the relation of phosphorus, lead, and zinc concentrations to the concentration of particulate matter reported in field studies.

Previous studies indicate that flow-attenuation basins are more effective in removing the particulate phase than the dissolved phase of chemical constituents (Striegl and Cowan, 1987). In this study, only the removal of particulate phosphorus, lead, and zinc was analyzed. Phosphorus was analyzed because it is a major nutrient for growth of aquatic plants and algae and because a reduction of phosphorus loads to Irondequoit Bay would improve its eutrophic status. Lead and zinc were analyzed because they are potentially toxic to a variety of biota and were found in elevated concentrations in Irondequoit Creek during 1980-81 (Kappel and others, 1986).

Particulate phosphorus, lead, and zinc were assumed to settle in proportion to the settling of suspended sediment. Because only total lead and zinc loads were available from the NURP study, the particulate concentration of these constituents were estimated on the assumption that the ratio of the particulate concentration to total concentration for the basins in this study is the same as the average ratio of particulate to total concentration measured quarterly in the adjacent Genesee River basin by the U.S. Geological Survey during 1978-82 (U.S. Geological Survey, 1979-83). The average ratio of total lead and zinc to suspended lead and zinc in the Genesee River near Rochester was then applied to the total annual loads measured at each site in the Irondequoit Creek basin during the NURP study. Two further assumptions were made--that dissolved forms of these constituents are nonreactive and pass through the flow-attenuation basin without retention, and that particulate forms of the constituents are equally distributed among the different sediment-particle sizes.

The assumptions of this method entail a degree of uncertainty; therefore, the retention efficiencies calculated for the Irondequoit basins were compared with those reported in field and laboratory studies of flow-attenuation basins by Brown and others (1981), Rausch and Schreiber (1981), Hey and Schaefer (1983), and Whipple and Hunter (1981).

Sediment Bedload

Flow-attenuation basins cause settling of suspended particulate material entrained in storm runoff by reducing the kinetic energy of the water. With reduced stream energy, bedload material (the coarse particles swept along the streambed by rolling, sliding, and skipping) would probably aggregate in a flow-attenuation basin and eventually decrease its storage capacity.

Bedload in the cobble-gravel streambeds at the Thornell, Linden, and Allen sites was assumed to represent 5 percent of the suspended-sediment load, from the ratio of bedload to suspended-sediment load reported for similar streambeds by Burrows and others (1981) and Jones and Seitz (1980). Bed material at the Blossom site consists of more uniform, sand-size particles that are more readily transported and was assumed to represent 20 percent of the suspended-sediment load on the basis of calculated values for similar streambeds (H. H. Stevens, U.S. Geological Survey, oral commun., 1988).

Basin Sedimentation

The rate at which the basins would become filled with sediment was calculated from empirical relations developed by Lara and Pemberton (1963) for bedload and for suspended sediment in normally pooled and dry reservoirs. The relation converts average unit weight of incoming sediments to a sediment volume by the following equation:

$$\gamma = W_c P_c + W_m P_m + W_s P_s,$$

where γ = weight of sediment per cubic foot of volume;
W = constants determined by regression analysis with dimensions of unit weight of clay, silt and sand;
P = fraction of total sediment, percentage by weight of clay, silt and sand; and
c,m,s = subscripts denoting clay, silt, and sand, respectively.

The regression constants (W) for clay, silt and sand, reported by Lara and Pemberton for maximum- and temporary-storage basins and bedload are:

	Number of observations	Particle size		
		Clay	Silt	Sand
Maximum storage pool	262	26	70	97
Temporary storage pool	405	40	12	97
Bedload	187	60	73	97

Particle-size distributions of suspended sediment were obtained from the mean particle size discussed in the section on sediment characteristics farther on; bedload particle-size distribution was assumed to represent sand-size particles or larger. The predicted annual sediment loads trapped in a basin can be converted to a volume from the density to estimate the annual loss of storage capacity.

STREAMFLOW AND WATER-QUALITY CHARACTERISTICS USED IN SIMULATIONS

Constituent loads in each basin vary from year to year, season to season, and storm to storm. Many factors affect the entrainment of constituents in streams and the deposition of constituents in a flow-attenuation basin. Of particular importance are (1) discharge and its relation to suspended-sediment concentration, and (2) particle-size distribution of sediments and its relation to chemical constituents.

Annual and Monthly Streamflow

Annual runoff measured at or near the flow-attenuation sites for the 1981 water year (October 1, 1980 to September 30, 1981), during which most of the NURP data were collected, averaged 31.6 ft^3/s for Irondequoit Creek at Thornell Road, 61.8 ft^3/s for Irondequoit Creek at Linden Ave., 26.4 ft^3/s for Allen Creek, and an estimated 110 ft^3/s for Irondequoit Creek at Blossom Road. Of the four sites, Allen Creek has the longest discharge record and therefore was used to compare long-term discharge trends with 1981 discharge. Mean annual discharge for the 1981 water year was the 7th lowest in 24 years of record (1961-84), and precipitation was 4.6 in. above the average computed from 40 years of record collected by the National Weather Service at Rochester. These statistics indicate runoff during the 1981 water year to be about average.

The duration and seasonal timing of stormflows also greatly affect the performance of a flow-attenuation basin. For example, runoff during the snowmelt period, usually between February and March, accounted for one-third of the total annual runoff and about 50 percent of the total annual load for seven of the eight principal constituents monitored from August 1980 through August 1981 in each basin (Kappel and others, 1986). Comparison of 1981 discharges at Allen Creek with long-term mean daily discharge (fig. 5) shows that

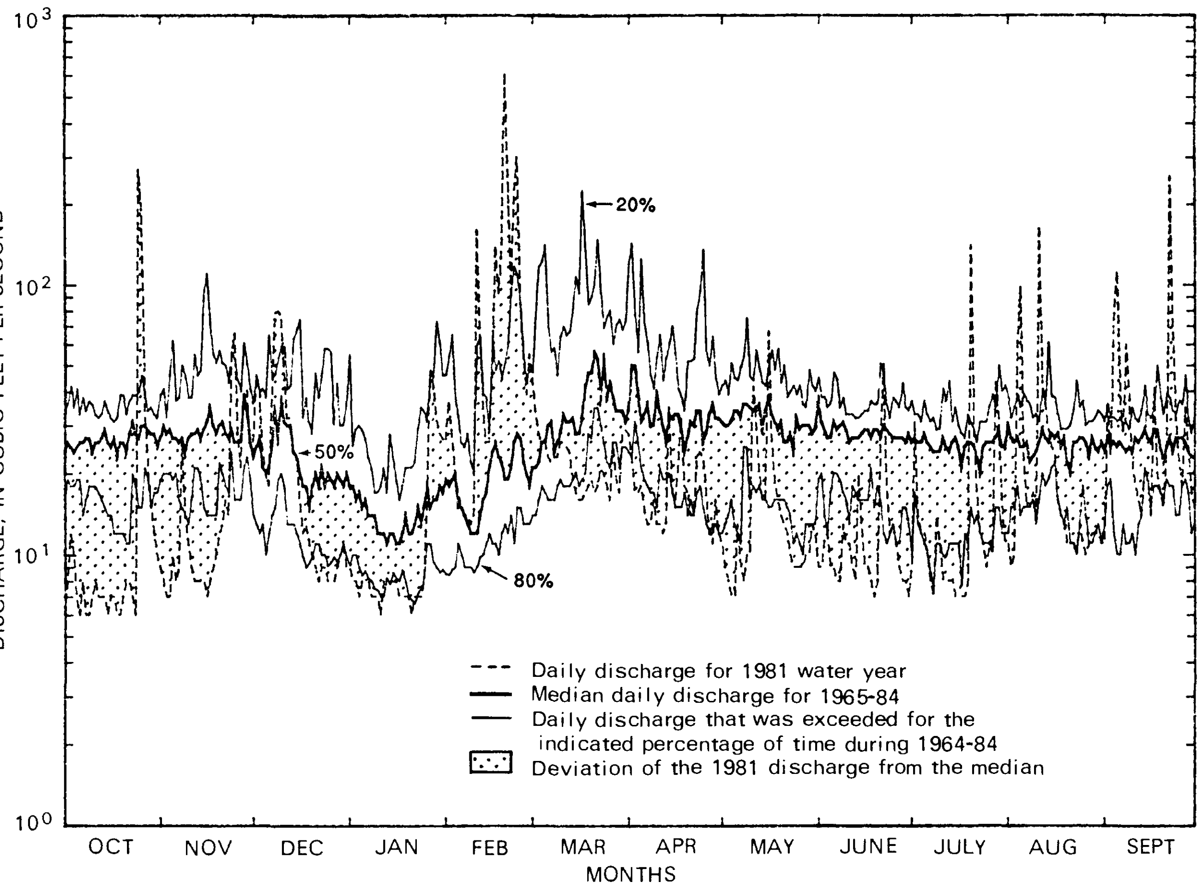

Figure 5.--Discharge of Allen Creek near Rochester (station 04232050) during 1981 water year in relation to long-term discharge records.

discharges during most of February greatly exceeded the median discharge of March because of an early spring thaw. Short-duration stormflows occurred frequently between May and September 1981, which is typical for that time of year. A large stormflow occurred in late October, and discharges above the median occurred during most of late November and early December. Discharges for the remainder of the year were relatively low--less than the discharge that is equaled or exceeded 80 percent of the time.

Characteristics of Selected Stormflows Used For Simulations

Three or four stormflows were selected for simulation at each of the four sites on the basis of (1) availability of water-quality data, (2) the discharges' representativeness of the different seasons, and (3) magnitude of the discharge. Characteristics of the selected stormflows used in the flow-attenuation simulations are summarized in table 2.

The selected stormflows represent a range of discharges and concentrations of suspended sediment. The storm of February 19-20, 1981, produced the highest peak discharge and longest sustained high flow (fig. 5) of any that year at all sites. Discharge before that storm was also high; thus, the storage capacity and the predicted detention time in the basin would be reduced. The predicted trap efficiency during this storm represents the lower limit of basin performance, which generally would occur during the snowmelt period. The July, August, and September stormflows were of short duration, typical for that season.

Flow-duration curves (Searcy, 1959) were developed for each site from mean daily discharge values derived from all records available through 1984 (fig. 6). The distribution of flow is based on the percentage of time a

Table 2.--Characteristics of selected storms used for simulations.

[Site locations shown in fig. 1. Discharges in cubic feet per second.]

Site	Storm date begin	Storm date end	Runoff (inches)	Peak Discharge	Maximum average daily discharge	Discharge at beginning of simulation
	9-1-80	9-3-80	0.12	133	81	18
Thornell	2-20-81	2-26-81	1.20	468	366	114
	7-20-81	7-24-81	.09	47	32	13
	8-4-81	8-9-81	.13	72	52	15
	9-1-80	9-6-80	.17	482	240	29
Linden	2-20-81	2-24-81	.80	724	590	283
	7-20-81	7-25-81	.09	221	106	19
	8-4-81	8-7-81	.07	125	81	21
	2-20-81	2-26-81	2.74	1,035	620	87
Allen	7-20-81	7-23-81	.32	417	140	10
	8-4-81	8-7-81	.31	314	99	11
	2-19-81	2-25-81	1.33	1,268	1,080	392
Blossom	7-19-81	7-25-81	.15	617	260	34
	8-4-81	8-7-81	.11	358	205	37

specified discharge is equaled or exceeded. The curve can be used to compare discharge from the selected storms with long-term discharges of the stream. Although discharge records for the Thornell and Blossom sites are of insufficient length for reliable statistical use, the storm discharge plotted on the respective station's duration curve indicates the relative magnitude of that storm. The February 1981 storm produced the highest mean daily discharge of the study, which would be exceeded less than 1 percent of the time; the rest were more typical summer stormflows that would be exceeded between 3 and 60 percent of the time.

The volume of storm runoff is also a major factor in the basin's trap efficiency because it affects the detention time. The frequency of occurrence of storm-runoff volume within given periods can be derived from Log-Pearson Type III analysis. Maximum stormflow volumes for 1-, 3-, and 7-day periods were computed for the selected storms at the Linden and Allen sites, and recurrence intervals were calculated through Log-Pearson Type III analysis (U.S. Geological Survey computer program, Weeks, 1984). Except for the February stormflow, all had recurrence intervals of less than 1 year; the recurrence intervals for the February discharge ranged from 1.2 to 8.8 years (table 3).

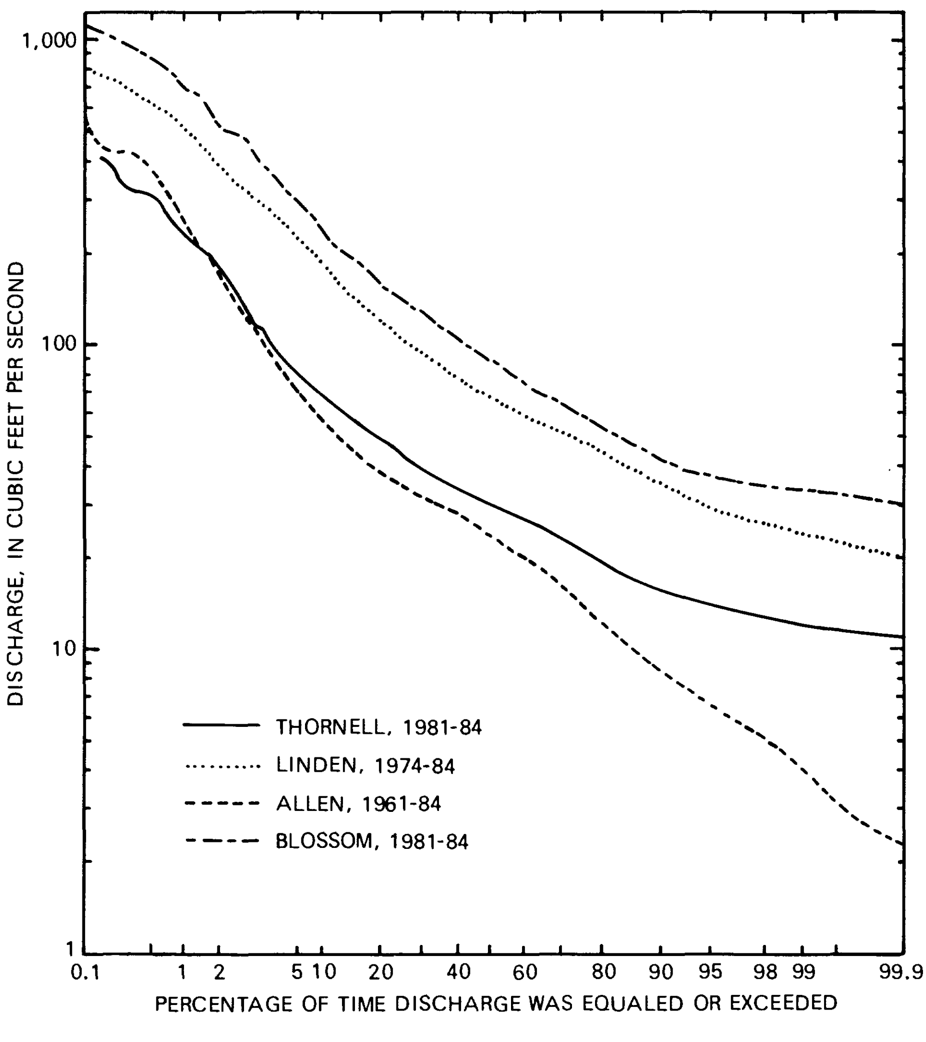

Figure 6.

Flow-duration curves for the four basin sites. (Site locations are shown in fig. 1.)

Because the recurrence interval of the February stormflow was significantly greater than 1 year, the trap efficiencies predicted for this storm may be applicable to even more severe storms, and the trap efficiencies during years of more normal stormflows may be somewhat greater than estimated.

Sediment Characteristics

The sediment transported by a stream consists of the fine fractions in suspension, the suspended-sediment load, and the heavy, coarse fractions that are swept along the stream channel (the bedload).

Table 3.--Mean, maximum, 1-, 3-, and 7-day discharge for the February 1981 storm and corresponding recurrence intervals derived from Log-Pearson Type III analysis.

[Site locations shown in fig. 1; discharges are in cubic feet per second.]

		1-day		3-day		7-day	
Site	Storm	Discharge	Recurrence interval (years)	Discharge	Recurrence interval (years)	Discharge	Recurrence interval (years)
Linden	2-20-81 to 2-24-81	590	1.2	490	1.4	400	1.9
Allen	2-20-81 to 2-26-81	620	4.3	340	3.7	250	8.8

Suspended-Sediment Concentrations

Suspended-sediment concentrations were measured over a range of discharges at the four basin sites during the 1980-81 NURP study (Zarriello and others, 1985); concentrations ranged from less than 10 mg/L to almost 1,000 mg/L. These data were used to develop a linear regression relation between discharge and suspended-sediment concentrations by which a continuous suspended-sediment concentration was calculated for inflow for use in the model simulation. The regression equations developed from suspended-sediment concentration as the dependent variable and instantaneous discharge as the independent variable are summarized in table 4 along with the strength of the correlation (r^2 or coefficient of determination) and the standard error of estimate. Some predicted concentrations for simulated storms were adjusted to match observed concentrations if the concentrations differed by more than 5 percent.

Particle-Size Distribution

Size distribution of particles suspended in streamflow varied during individual storms, as well as from storm to storm and site to site. Factors that affect particle-size distribution include the type of source material,

Table 4.--Regression equations† used to develop suspended-sediment concentrations.

[Site locations shown in fig. 1.]

Site	Number of obser-vations	Regression equation	$*r^2$	Standard error**
Thornell	49	Log c = 1.23 (log Q)	0.95	0.50
Linden	54	Log c = 1.12 (log Q)	.98	.27
Allen	102	Log c = .994 (log Q)	.96	.36
Blossom	87	Log c = .929 (log Q)	.98	.30

†Regression equations were forced through the origin, which resulted in a zero intercept that was dropped from the equation. Q is the instantaneous stream discharge, in cubic feet per second. Log c is the concentration of suspended sediment, in milligrams per liter.

$*r^2$ = measure of the strength of the linear correlation between variables.

**Standard error for estimates of the mean value of Y (suspended sediment) for a particular value of X (discharge) by the regression equation. The standard error is in log units.

physical features of the stream such as slope, cross-sectional area, and discharge, antecedent conditions, and land use. The discharge-weighted mean particle-size distribution at the four sites ranged from 10 to 20 percent sand, 47 to 56 percent silt, and 30 to 43 percent clay (Kappel and others, 1986), as calculated from the discharge-weighted mean distribution (fig. 7). Generally, this approximates the particle-size distribution of the predominantly silt-loam soils of the Irondequoit Creek basin. The discharge-weighted mean particle size for eight size classes was used as a basis for model simulations at each site. Simulations also were run that included (1) maximum sand and minimum clay content, and (2) minimum sand and maximum clay content (shown as hatched bars in fig. 7) to test the sensitivity of model predictions to the particle-size-distribution range measured during the NURP study at each site.

The percentage of sand-, silt-, and clay-size particles in suspension plotted against discharge suggest that, as discharge increases, the proportion of sand also increases and the proportion of clay decreases. An opposite and unexpected trend was observed at the Linden site, which suggest that the proportion of clay increases and the proportion of sand decreases as discharge increases. The percentage of silt at all sites remains fairly constant throughout the range of discharges. This pattern suggests that, except for the Linden site, the model probably underpredicts the trap efficiencies slightly because it assumes a constant particle-size distribution. At low discharges, the percentage of clay-size particles is larger and detention time greater than at higher flows, which allows more of the fine fractions to settle. Conversely, as discharge increases, the percentage of sand particles increases, the detention time decreases, and the settling of fine particles decreases. If the opposite trend observed in the Linden site is correct, the model may overpredict particulate settling.

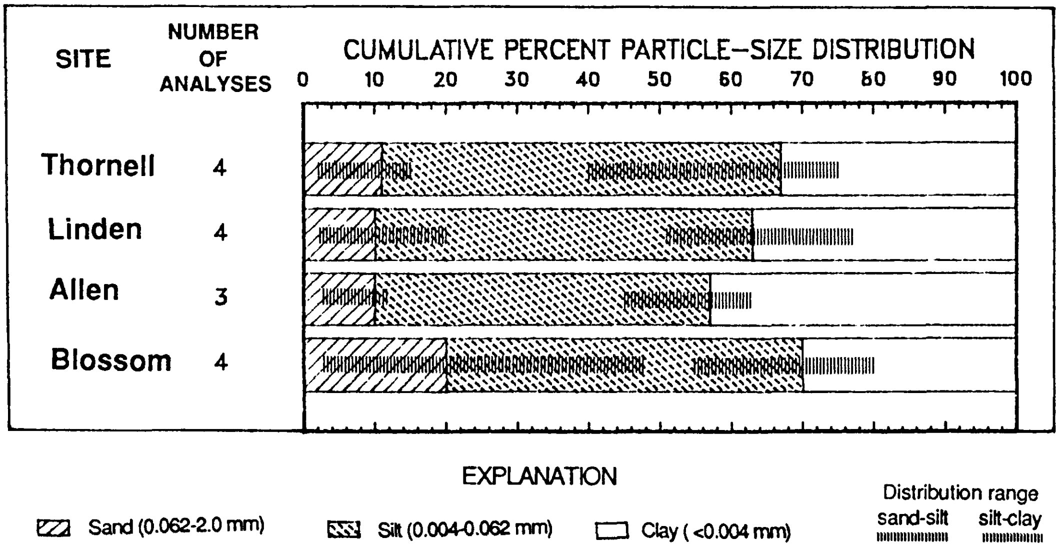

Figure 7.--Particle-size distribution of suspended sediment obtained from August 1980 through August 1981. Values are discharge-weighted averages and range of measured particle-size fractions.

Phosphorous, Lead, and Zinc

Storm loads, seasonal loads, and annual loads of total and dissolved phosphorus and total lead and zinc at the four sites are described by Kappel and others (1986), who found that snowmelt and spring runoff transported 50 percent of the total annual phosphorus load, 70 percent of the lead, and 60 percent of the zinc. Stormflows during the remainder of the year transported about 20 percent of the remaining load.

The suspended lead and suspended zinc concentrations at the study sites were estimated from the observed ratio of suspended to total concentration at the Genesee River, which indicates that 73 percent of the lead and 62 percent of the zinc occur in the particulate phase. Estimated values at the study sites are summarized in table 5. The ratio of particulate phosphorus to total phosphorus in the nearby Genesee River was also calculated and compared with that observed in the Irondequoit watershed to provide an indication of the transferability of the data. Results indicated that 49 percent of the total phosphorus in the Genesee River was in the suspended form, whereas in the Irondequoit Creek watershed, 72 to 91 percent of the total phosphorus was in the suspended form. This indicates that the use of ratios from the Genesee River could introduce error into the estimation of lead and zinc retention in the Irondequoit basin and also suggests a higher percentage of particulate lead and zinc in the Irondequoit Creek basin than in the Genesee River. An underestimation of particulate concentrations would result in an underprediction of metals retention.

To obtain an accurate ratio of particulate lead and zinc to total lead and zinc at the four Irondequoit sites would require further sampling and analysis of both the total and dissolved phase of these constituents, but this was beyond the scope of the study.

The correlation between suspended-constituent concentrations and particle-size fractions has not been extensively studied, but the available data show larger proportions of particulate phosphorus, lead, and zinc on the clay-size particles than on other sizes because of the clay's relatively large surface area and large cation-exchange capacity. The amount of phosphorus sorbed to clay minerals will depend on the phosphorus concentration and the available cation-exchange sites to react with the sorbed phosphorus (White, 1981). Rausch and Schreiber (1981) found that clay, which forms 15 percent of the sediment load, contained 23 percent of the particulate phosphorus. Carter and others (1974) found the concentration of total phosphorus attached to the sand, silt, and clay fractions in an Idaho drainage pond to be 550, 1,150, and 1,285 parts per million, respectively. This shows that about half as much phosphorus is associated with the sand-size particles as with clay-size particles. In a study of the same pond, Brown and others (1981) reported approximately 60 percent less phosphorus retention than sediment retention, which corresponds to the ratio of phosphorus concentration on sand particles to that on clay-size particles.

Fine-grained sediments are the main sites for metal adsorption (Jenne, 1968; Gibbs, 1973) because their large surface areas provide a mechanical substrate upon which metals can concentrate without chemical interactions occurring (Jenne, 1976). Metals also will accumulate on other substrates, including sand particles (Filipek and others, 1981; Robinson, 1982), but in lower concentrations (Horowitz, 1984).

Results of these and other studies are site specific. To examine the relation between adsorbed constituent concentrations and particle size in the Irondequoit basin, data on particulate phosphorus, total lead, and total zinc concentrations were log transformed and plotted against sand-, silt-, and clay-size fractions (A. J. Horowitz, U.S. Geological Survey, oral commun., 1987). Plots based on eight samples collected at the four basin sites during the NURP study show a positive correlation between phosphorus concentration and percentage of clay-sized material, but no similar correlation for lead and zinc. This observation, and results described from the literature, suggest that particulate phosphorus is not retained in equal proportions among particle-size classes; thus, the assumption that particulate forms of constituents are

Table 5.--Estimated mean and range of suspended lead and zinc concentrations.

[Site locations shown in fig. 1. Number in parentheses represents number of observations used to determine suspended proportion of total load and zinc concentrations.]

Constituent		Thornell	Linden	Allen	Blossom
Suspended lead (micrograms per liter)	Max	70 (77)	67 (73)	205 (71)	101 (102)
	Min	1	1	4	1
	Mean	6	12	37	20
Suspended zinc (milligrams per liter)	Max	9.30 (66)	6.20 (62)	2.60 (70)	3.72 (89)
	Min	.012	.012	.012	.019
	Mean	.639	.503	.358	.340

equally distributed among different size classes may result in an overestimation of phosphorus retention by the model. Although no correlation was found between metals concentration and particle-size distribution, the literature indicates that such a relation generally exists (Jenne, 1968; Gibbs, 1973); therefore, the retention of lead and zinc also may be overestimated.

Results of previous studies and plots of bulk-chemistry data against grain-size distribution provide only a general indication of the relation between adsorbed-constituent concentration and grain-size distribution. A chemical analysis of each size fraction would be needed to determine the proportion of a constituent associated with that particle-size fraction before accurate calculations of the constituent-retention rates could be made. This information was unavailable, however; thus, the estimated retention rates reported here may differ considerably from the actual values.

RESULTS OF SIMULATIONS OF CHANGES IN STORMFLOW QUALITY

Basin Outflow

Storm discharges measured during the NURP study are plotted along with simulated discharges from both types of basins at each site in figures 8A through 8D; the measured and predicted suspended-sediment concentrations (discussed in the next section) are included for comparison. Simulated flows at the Thornell site indicate a greater decrease in peak flow and more prolonged recessions in maximum-storage basins than in temporary-storage basins. Conversely, the Linden and Allen sites show more attenuated peak flows and longer recessions in temporary-storage basins. Temporary-storage basins normally have a larger potential storage capacity; therefore the attenuation of flow in these basins will generally be greater than in maximum-storage basins. Flow attenuation at the Thornell site was greater because the storage capacity rapidly increased above the 405-ft pool elevation (fig. 2), which was not exceeded in temporary-storage basins. The attenuation of flow at the Blossom site was greater in the maximum-storage basin than in the quarry because it is a larger permanent-storage pool. In all basins, on a percentage basis, flows of shorter duration and lesser magnitude showed greater attenuation of peak flows and more extended recessions than high flows (those with a low probability of recurrence, such as that of February 1981).

The decrease in peak discharge (table 6) for each simulated storm at each site ranged from 0.5 to 39 percent for temporary-storage basins and from 0 to 46 percent for maximum-storage basins. The peak outflows lagged behind the peak inflows by 1 to 10 hours. The delay and magnitude of reduction of peak discharge and length of recession are a function of (1) the ratio of basin storage capacity to contributing drainage area, (2) the magnitude of the storm, and (3) the configuration of the control.

Simulated pool elevations were highest during the February 1981 storm at all sites and were greater in maximum-storage basins than in the temporary-storage basins; the values are included in table 6 (p. 29). The areas that would be inundated at each site at these elevations are shaded in figures 9A, 9B, and 9C.

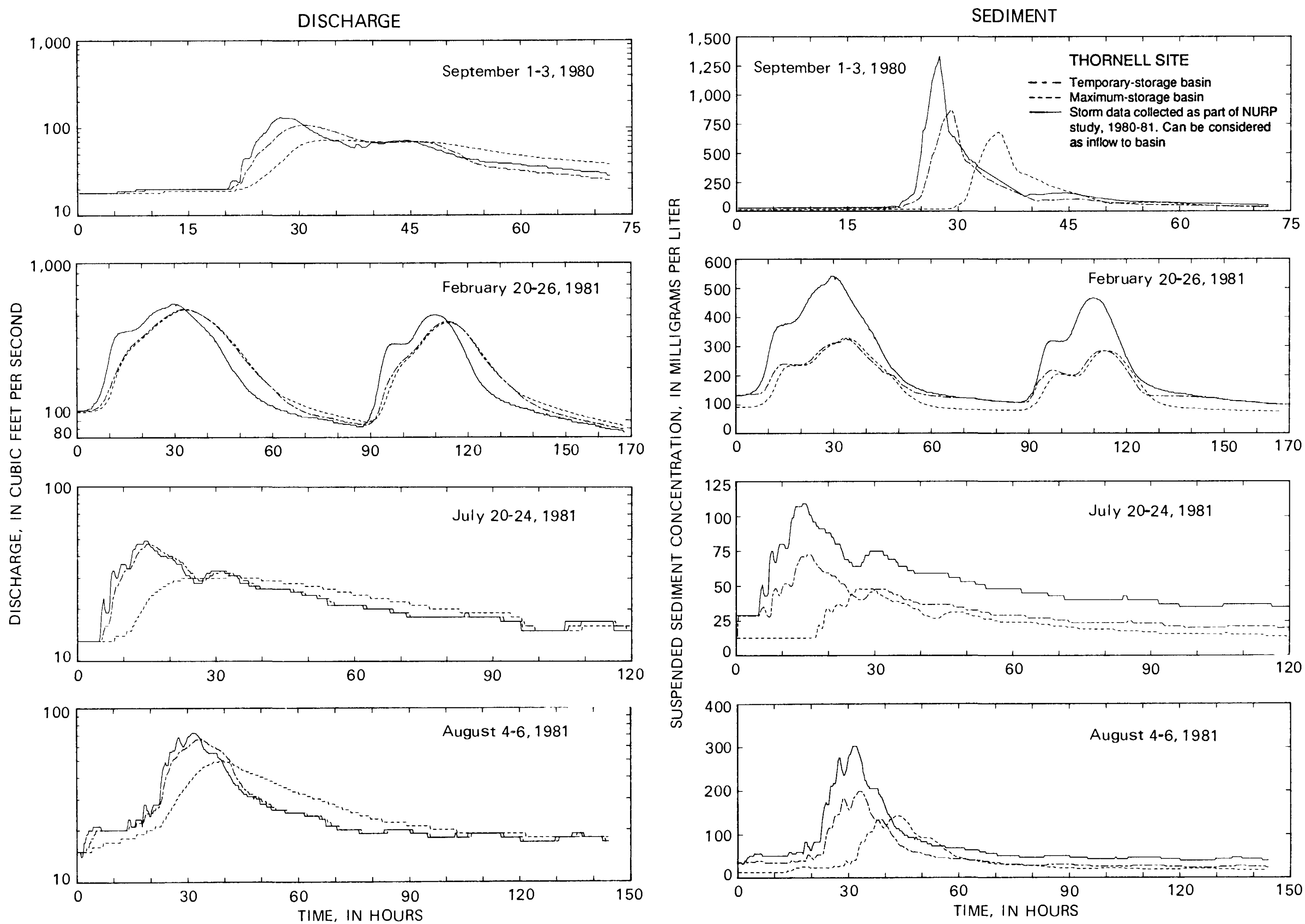

Figure 8A.--Measured and simulated storm discharge and suspended-sediment concentrations at the Thornell site.

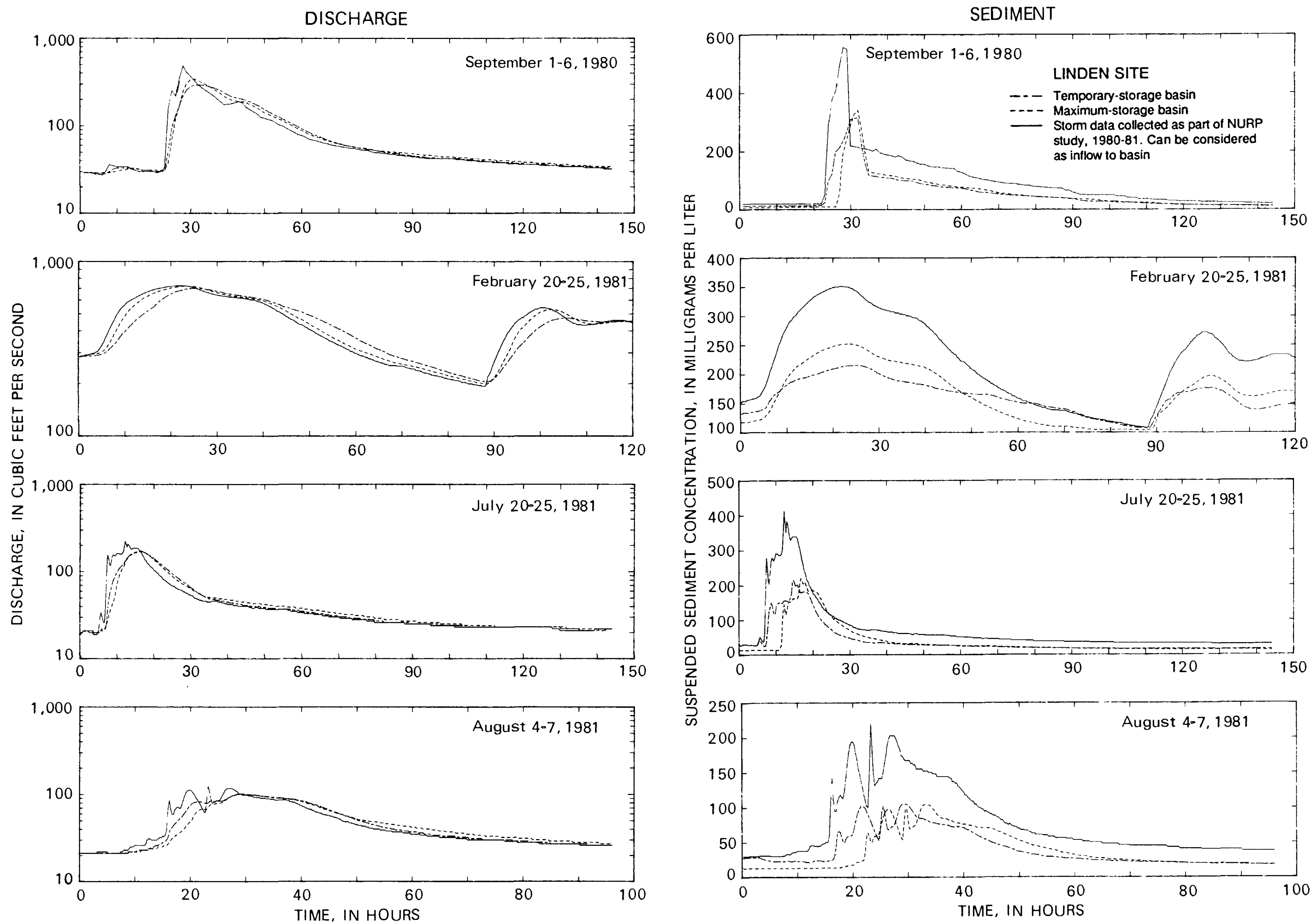

Figure 8B.--Measured and simulated storm discharge and suspended-sediment concentrations at the Linden site.

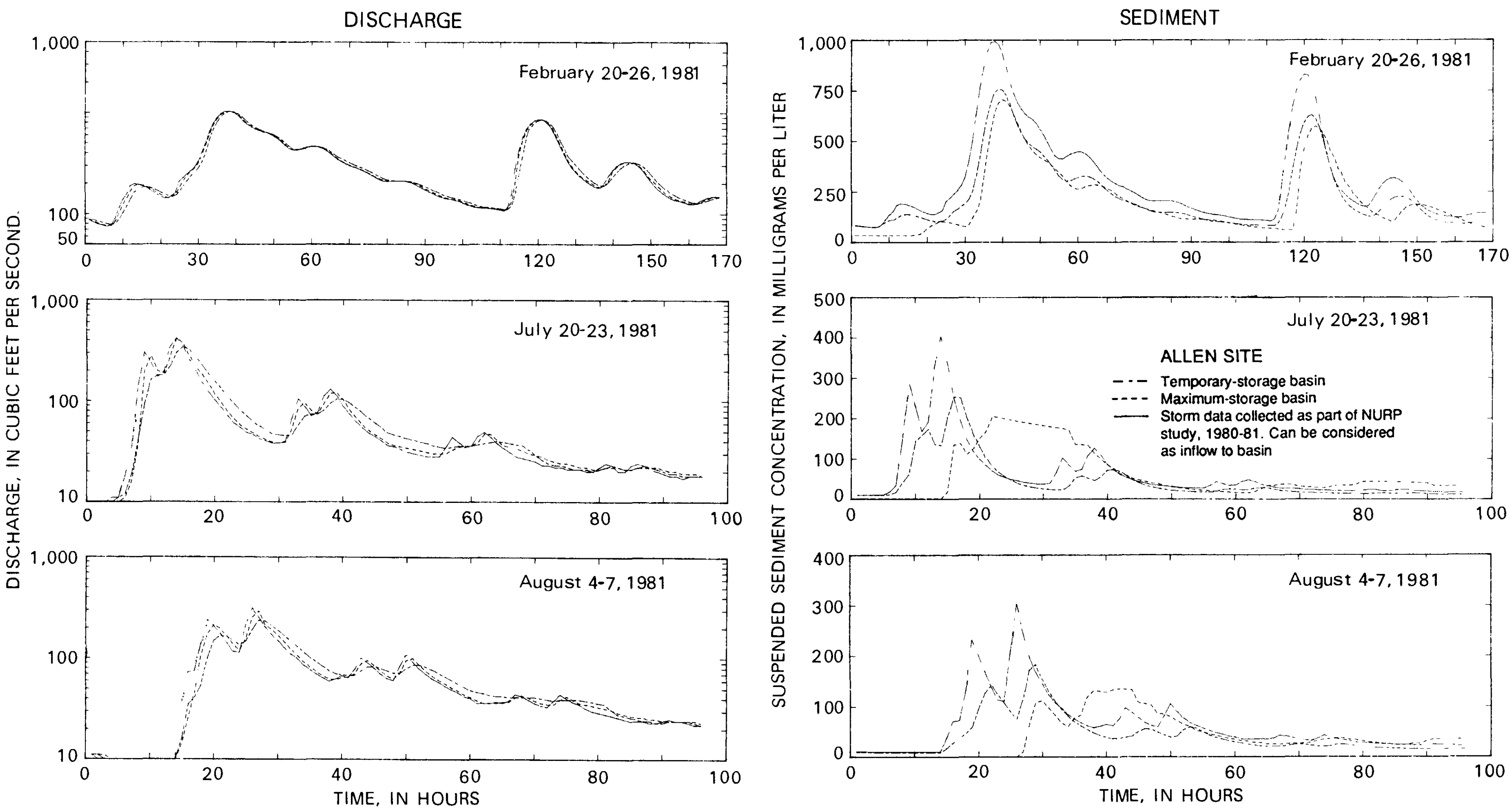

Figure 8C.--Measured and simulated storm discharge and suspended-sediment concentrations at the Allen site.

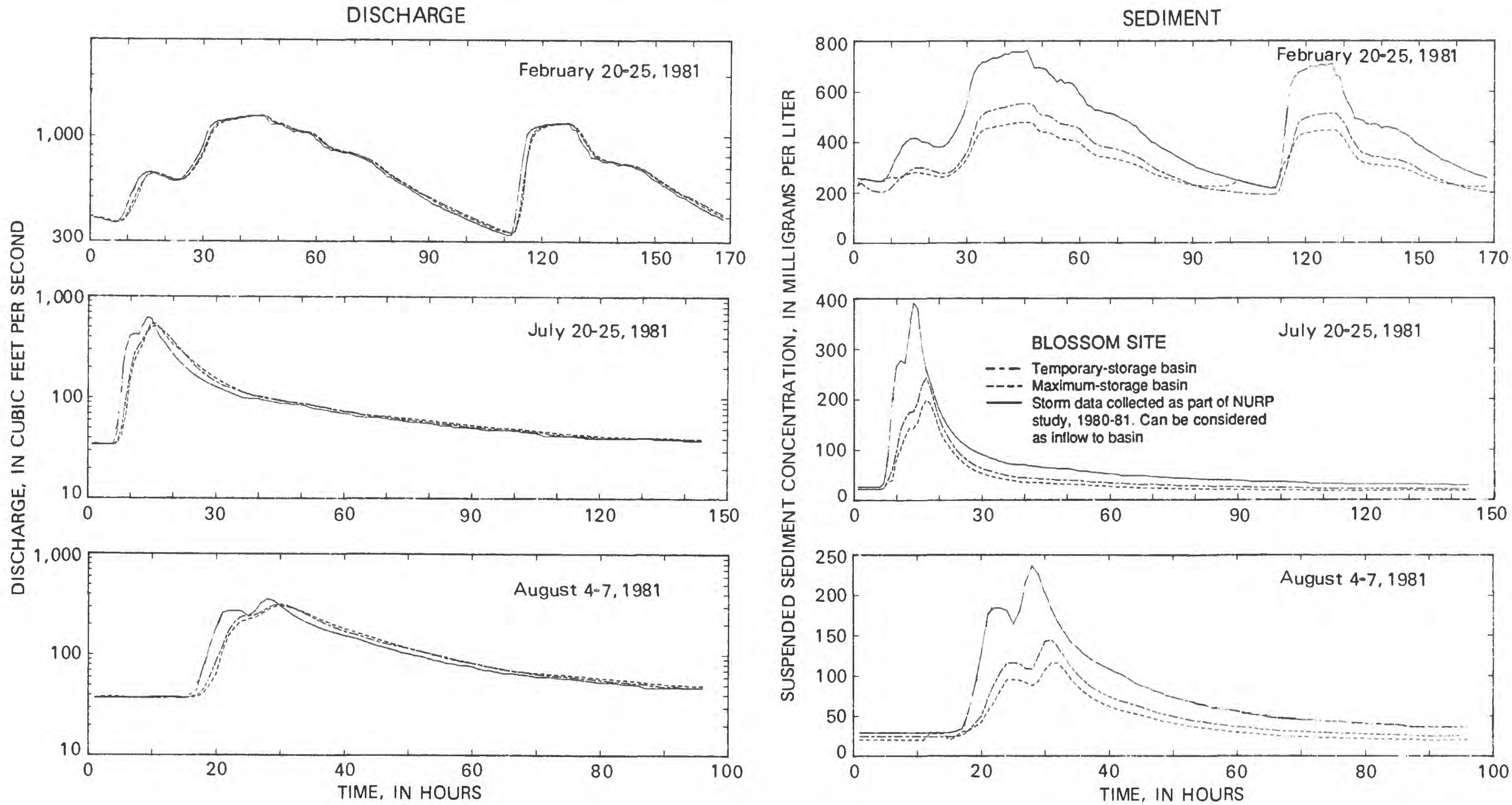

Figure 8D.--Measured and simulated storm discharge and suspended-sediment concentrations at the Blossom site.

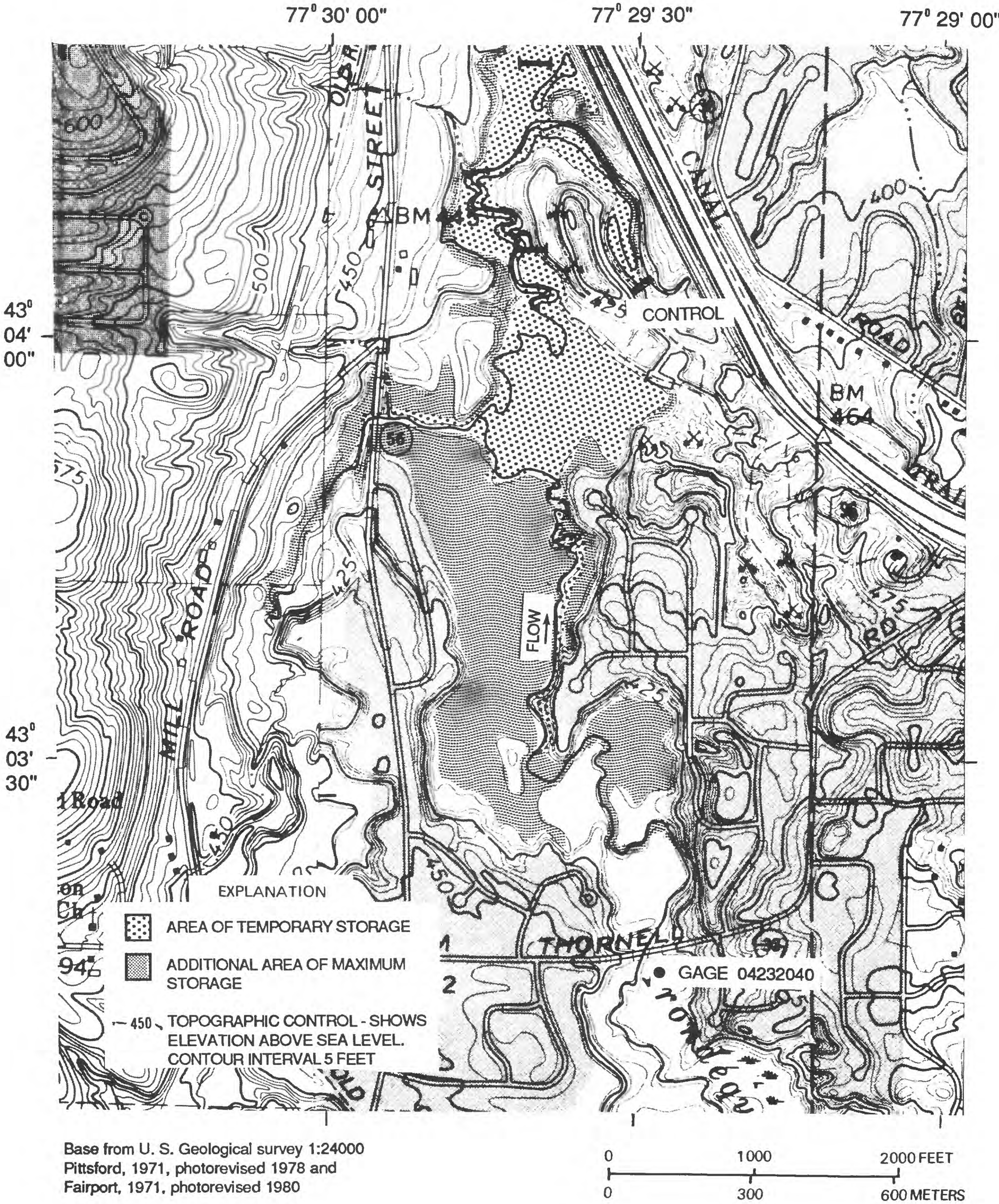

Figure 9A.--Approximate area of inundation predicted for February 1981 stormflow at temporary- and maximum-storage basins at the Thornell site. (Location is shown in fig. 1.)

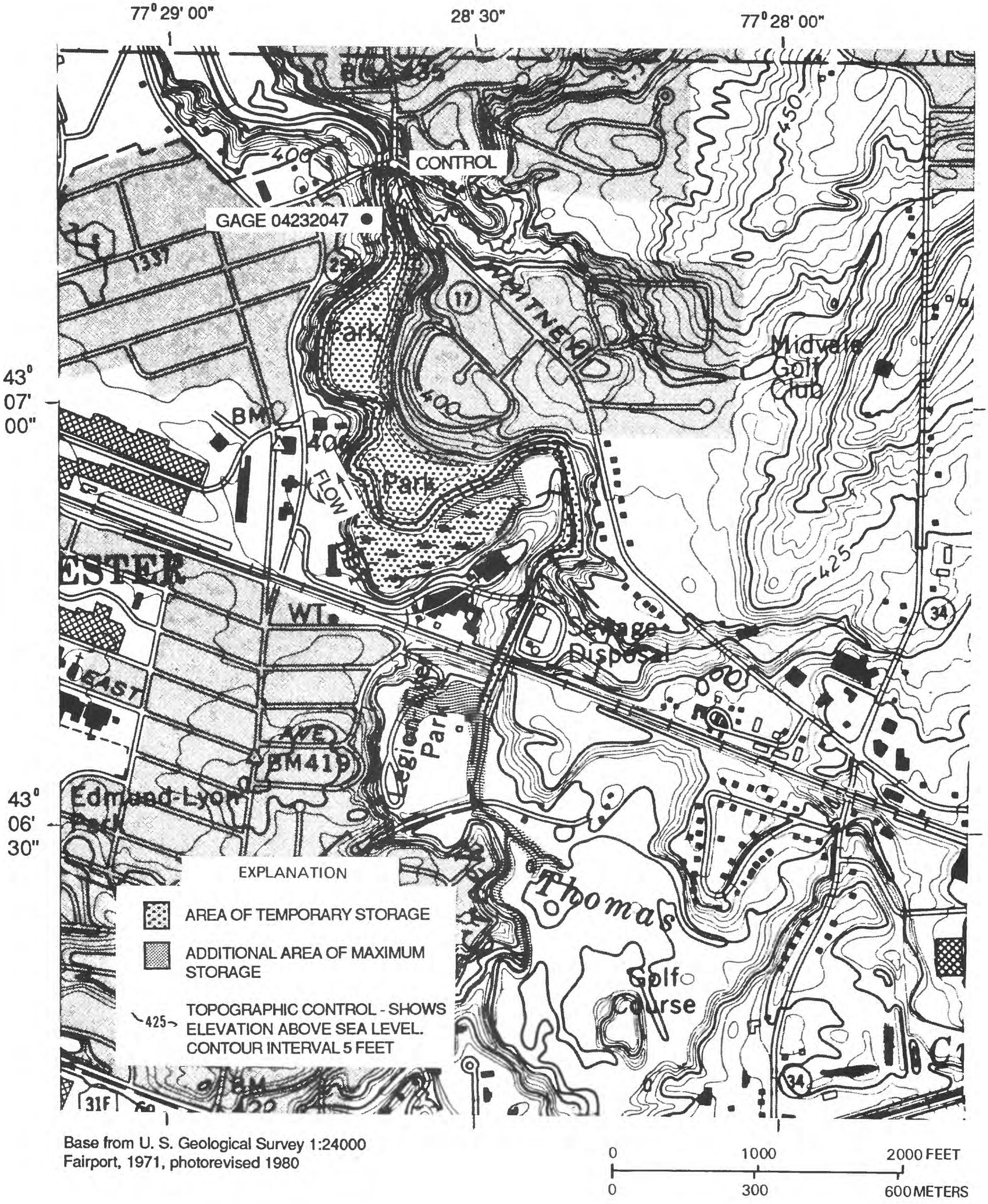

Figure 9B.--Approximate area of inundation predicted for February 1981 stormflow at temporary- and maximum-storage basins at the Linden site. (Location is shown in fig. 1.)

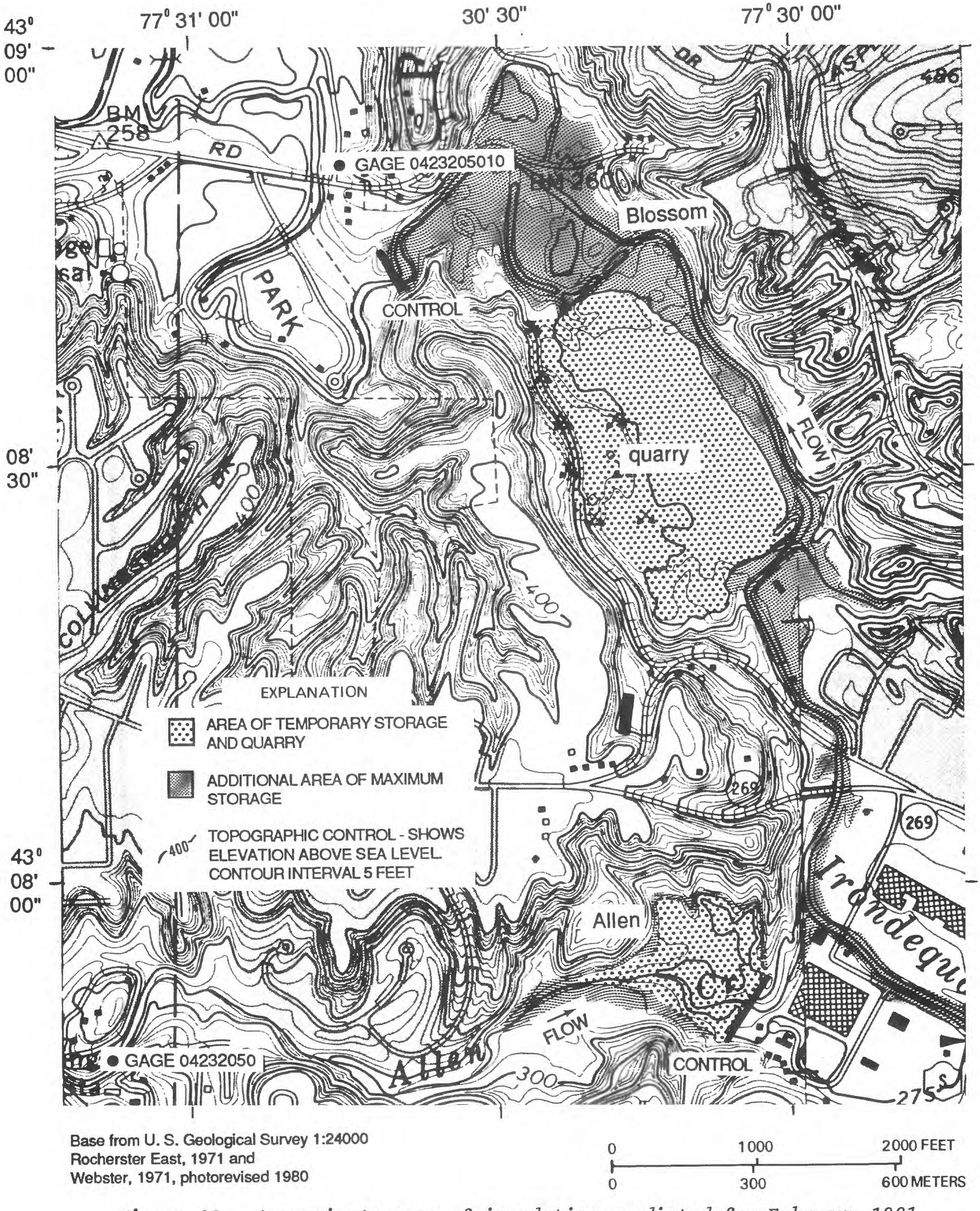

Figure 9C.--Approximate area of inundation predicted for February 1981 stormflow at temporary- and maximum-storage basins at the Allen site and the quarry and maximum-storage basins at the Blossom site. (Location is shown in fig. 1.)

Table 6.--Stormflow characteristics at simulated flow-attenuation basins.

[Flows are in cubic feet per second; pool elevations are in feet above sea level. Site locations are shown in figs. 9A-9C.]

Site	Storm dates start	Storm dates end	Mean discharge	Peak inflow	Temporary-storage basins: Peak outflow	Temporary-storage basins: Percent reduction	Temporary-storage basins: Maximum pool elevation	Maximum-storage basins: Peak outflow	Maximum-storage basins: Percent reduction	Maximum-storage basins: Maximum pool elevation
Thornell	9-1-80	9-3-80	47	133	108	19	398.6	72	46	408.4
	2-20-81	2-26-81	200	468	436	7	404.2	468	0	410.6
	7-20-81	7-24-81	24	49	47	4	395.8	31	37	408.8
	8-4-81	8-9-81	26	72	67	7	396.8	50	30	409.0
Linden	9-1-80	9-6-80	80	482	294	39	360.9	340	29	370.7
	2-20-81	2-24-81	440	724	701	3	366.2	720	.6	371.0
	7-20-81	7-25-81	43	221	169	24	358.0	172	22	369.5
	8-4-81	8-7-81	48	125	100	20	355.9	117	6	369.2
Allen	2-20-81	7-26-81	230	1,035	1,025	1	283.3	1,034	.1	287.3
	7-20-81	7-23-81	50	417	342	18	279.7	416	.2	286.6
	8-4-81	8-7-81	50	314	233	26	278.5	280	11	286.4
Blossom	2-19-81	2-25-81	730	1,268	1,261	.5	255.6	1,259	.7	265.5
	7-19-81	7-25-81	87	617	512	17	254.0	457	26	264.9
	8-4-81	8-7-81	100	358	317	11	252.6	307	14	264.6

Pond stage in a temporary-storage basin will rise and fall more rapidly than in a maximum-storage basin. The more rapid the changes in stage, the less likely are particles to settle according to Stoke's Law because of turbulent flow. Thus, particles in temporary-storage basins will remain in suspension longer than predicted by the model, and particles that settle will be more subject to resuspension.

Sediment

The concentrations of suspended sediment in the inflow and simulated outflow of maximum- and temporary-storage basins at each site are illustrated in figures 8A-8D alongside the corresponding discharge plots. Predicted outflow concentrations of suspended sediment were proportional to the flow attenuation, but reductions in concentration were generally greater in maximum-storage basins and in basins having a large storage capacity in relation to drainage area. Moderate stormflows showed a greater reduction in sediment concentration than large stormflows.

Effects of storage.--The predicted sediment concentrations in basin outflow depend largely on how the model treats the volume of water in storage (dead storage) within the basin. The predicted outflow concentrations shown in figures 8A-8D are based on model simulations in which basin storage was set equal to the permanent pool capacity. When simulations are made in this fashion, water in the basin is bypassed, and outflow concentrations are higher than those that might occur if the water in storage were discharged. Alternatively, basin storage can be set to zero, and the initial simulated outflow concentrations will be low as a result of the release of "clean" water in storage from the basin. In general, the outflow concentrations will probably be between these two extremes (Alley and Smith, 1982). Because temporary-storage basins do not maintain a permanent pool of water, "dead" storage is not significant in these simulations.

Estimates of sediment retention in maximum-storage basins and the quarry are based on the average trap efficiency in simulations in which (a) water in storage was bypassed, and (b) water in storage was displaced. Simulations made with basin storage set equal to zero had, on the average, a 50-percent higher trap efficiency than those with basin storage set equal to permanent pool capacity. The difference was even greater in small stormflows because displacement of "clean" water from storage takes longer and allows a greater detention time for particulate settling. If basin storage were greater than the storm volume, the predicted outflow concentrations would remain low throughout the event.

Trap efficiency of basins.--The estimated trap efficiencies of maximum-storage basins were greater than those of temporary-storage basins by 84 percent at the Thornell site, 28 percent at the Linden site, and 8 percent at the Allen site. The trap efficiency of the maximum-storage basin at the Blossom site averaged 6 percent greater than that of the quarry. The suspended-sediment loads retained in both types of basins at each site are plotted in figure 10.

The predicted average trap efficiency for mean particle-size distribution at maximum-storage basins during moderate stormflows averaged 70 percent at the Thornell site, 63 percent at the Linden site, 39 percent at the Allen site, and 69 percent at the Blossom site, whereas trap efficiencies for the large February 1981 storm were 48 percent, 39 percent, 25 percent, and 52 percent, respectively. Trap efficiencies for mean particle-size distribution for moderate stormflows at temporary-storage basins averaged 35 percent at the Thornell site, 47 percent at the Linden site, 35 percent at the Allen site, and 68 percent at the quarry site. The trap efficiency of temporary-storage basins for the large February 1981 storm at the Thornell site was about the same as for moderate storms but decreased to 35 percent at the Linden site and 25 percent at the Allen site. Predicted trap efficiencies during base flows averaged between 52 and 80 percent for all maximum-storage basins, 71 percent at the Blossom quarry site, and less than 5 percent for temporary-storage basins. The predicted trap efficiencies in simulations made for variable particle-size distributions are presented in table 7 and discussed later in this section.

Detention time has been shown to be one of the most significant predictors of trap efficiency (Rausch and Heinemann, 1975; Rausch and Schreiber, 1981). In this study, the detention times averaged about 23 hours in maximum-storage basins and about 1.3 hours in temporary-storage basins. The average detention time for maximum-storage basins is the average between simulations in which water in storage is bypassed and those in which it is not. When water in storage is not bypassed, the detention time is about 94 percent greater, which results in the previously described differences in predicted trap efficiencies.

Detention time in maximum-storage basins was greater for stormflows of short duration and small magnitude than for large storms, but in temporary-storage basins, the large stormflows gave longer detention times than the smaller storms. The simulated "summer" stormflows of small magnitude in maximum-storage basins averaged 68 percent greater detention time than the large February 1981 storm, whereas the detention time in temporary-storage basins was 50 percent less for the "summer" storms than for the February storm. This inverse relation at temporary-storage basins is due to the design of the control, which increases retention as discharge increases. The extent to which detention time can increase in temporary-storage basins depends on the available basin storage and the magnitude and duration of flow. Also, alternative designs may reduce the effect of the physical constraints of the basin by enhancing sedimentation through baffles or flow retarders and constriction of a series of stages of ponds (Randall, 1982). These alternatives were beyond the scope of this project, however.

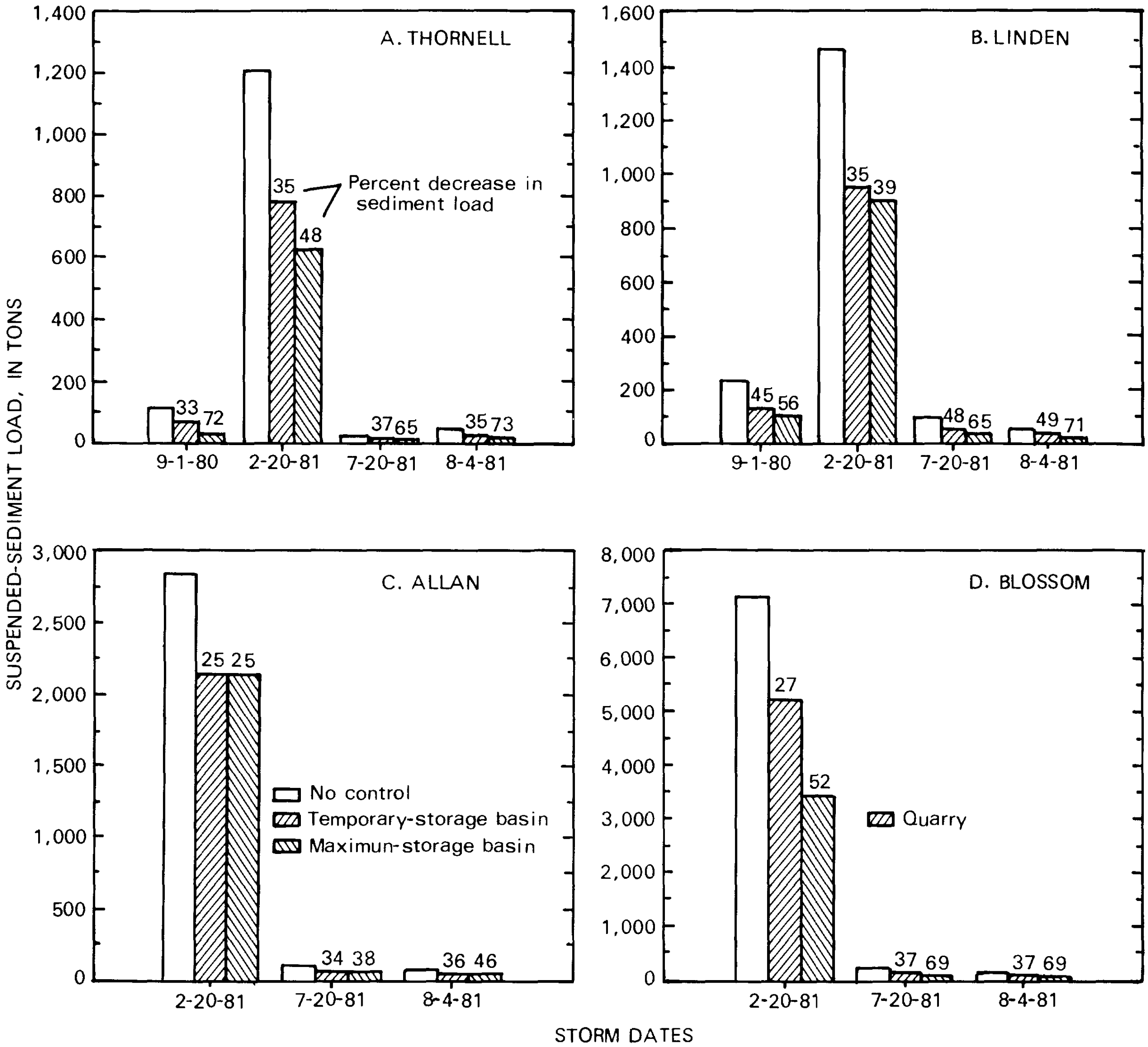

Figure 10.--Decrease in suspended-sediment loads in temporary- and maximum-storage basins for selected stormflows.

Table 7.--Suspended-sediment-trap efficiency of temporary- and maximum-storage basins during selected simulated stormflows.

[Site locations shown in fig. 1. Values are in percent.]

Site	Date of storm	Temporary-storage basin			Maximum-storage basin		
		Mean[1]	High[2] clay	High[3] sand	Mean	High clay	High sand
Thornell	9-1-80	33	21	58	72	66	84
	2-20-81	35	23	58	48	38	69
	7-10-81	37	24	60	65	70	86
	8-4-81	35	23	60	73	67	78
Linden	9-1-80	45	31	60	56	44	68
	2-20-81	35	23	49	39	28	52
	7-20-81	48	34	63	65	58	75
	8-4-81	49	36	64	67	59	79
Allen	2-20-81	25	16	34	25	16	33
	7-20-81	34	24	43	38	29	46
	8-4-81	36	26	46	40	32	48
Blossom	2-20-81	44	27	60	52	35	66
	7-20-81	68	58	78	69	64	84
	8-4-81	68	58	78	69	64	84

[1] discharge-weighted mean
[2] minimum sand and maximum clay distribution
[3] maximum sand and minimum clay distribution

The particle-size distribution of incoming sediment is a major factor in trap efficiency. Simulations in which the size classes of incoming sediment were varied (within the range of measured particle-size data) gave a wide range of trap efficiencies for both types of basins. Predicted trap efficiencies in simulations that used a high proportion of clay-size particles (table 7) averaged 20 to 30 percent lower than the mean, and those made with a high proportion of sand-size particles averaged 20 to 30 percent higher than the mean. The predicted trap efficiencies of temporary- and maximum-storage basins based on the measured mean and range of particle-size distributions are plotted in figures 11A and 11B, respectively.

As mentioned previously, the particle-size distribution of suspended sediment may vary with discharge. The proportion of sand-size particles may increase as discharge increases, which increases trap efficiency, and the proportion of clay-size particles may increase as discharge decreases, which decreases trap efficiency. Thus, the trap efficiency may be greater than predicted for an average particle-size distribution throughout a stormflow.

Annual Retention of Suspended Sediment

Annual trap efficiencies of temporary- and maximum-storage basins were calculated from seasonal suspended loads (table 8, p. 34) reported by Kappel and others (1986) and trap efficiencies based on mean particle-size

Figure 11A.

Relation of trap efficiency of simulated flow-attenuation basins to discharge and particle-size distribution at temporary-storage basins and quarry.

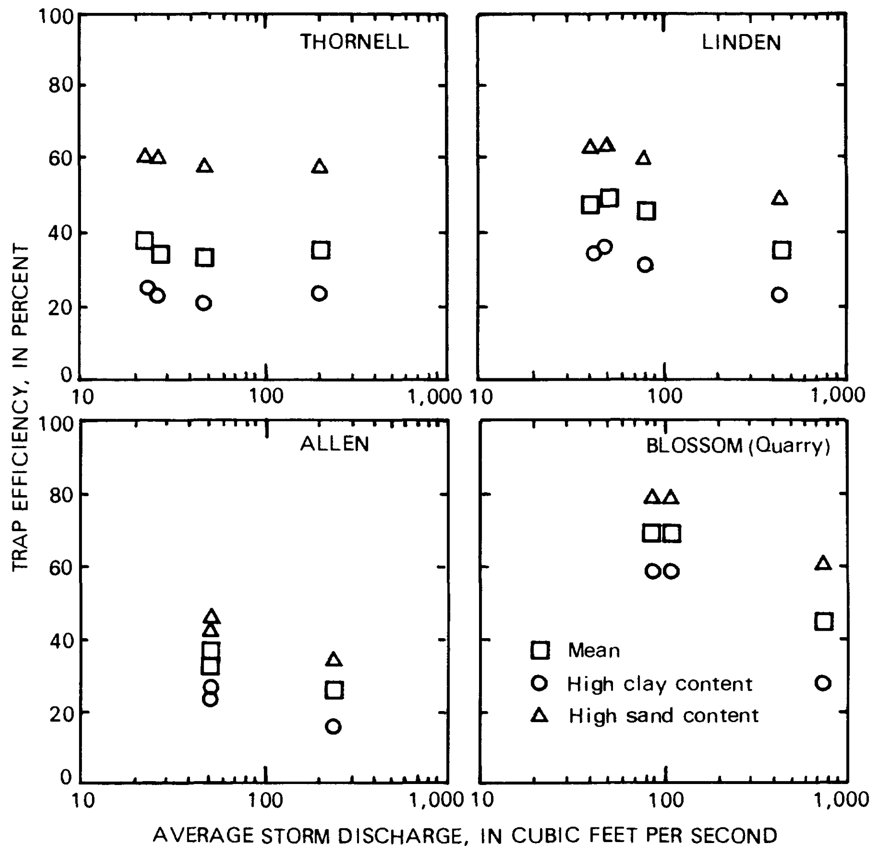

Figure 11B.

Relation of trap efficiency of simulated flow-attenuation basins to discharge and particle-size distribution at maximum storage basins.

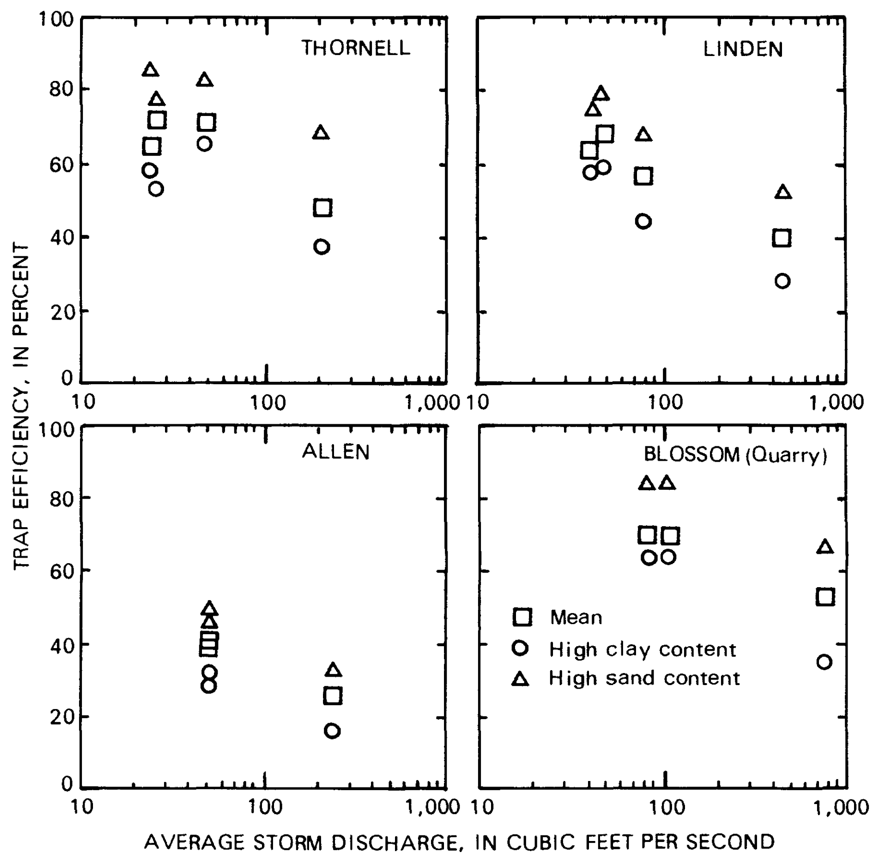

Table 8.--Estimated seasonal retention of suspended-sediment by flow-attenuation basins.

[Site locations shown in fig. 1.]

Period	Load[1] (tons)	Temporary storage basin: Estimated retention (percent)	Temporary storage basin: Load retained (tons)	Maximum storage basin: Estimated retention (percent)	Maximum storage basin: Load retained (tons)
		A. THORNELL			
Growing season					
Base flow	310	0	0	85	270
Storms	540	35	190	70	380
Winter	350	35	120	65	220
Snowmelt	2,500	35	880	48	1,200
Spring	50	35	20	67	30
Total for period	3,750	32[2]	1,210	56	2,100
		B. LINDEN			
Growing season					
Base flow	600	0	0	72	430
Storms	1,100	47	500	63	680
Winter	--	--	--	--	--
Snowmelt	3,100	35	1,100	39	1,200
Spring	110	47	50	63	70
Total for period[5]	4,910	34	1,650	48	2,380
		C. ALLEN			
Growing season					
Base flow	150	0	0	52	80
Storms	640	35	220	40	260
Winter	230	40	90	45	100
Snowmelt	1,300	25	320	25	320
Spring	80	40	30	45	40
Total for period	2,400	28	660	33	800
		D. BLOSSOM			
Growing season[4]					
Base flow	620	80[3]	490	85	520
Storms	1,600	68	1,000	74	1,200
Winter	1,300	72	970	72	970
Snowmelt	8,200	44	3,600	52	4,200
Spring	1,000	68	700	68	700
Total for period[5]	12,720	53	6,760	60	7,590

[1] Seasonal loads reported by Kappel and others (1986).
[2] Percent retention for total period obtained by dividing total load retained by the total load.
[3] Quarry at the Blossom site.
[4] No data prior to December 15, 1980.
[5] Partial year.

distribution for the range of discharges (fig. 11). The average reported seasonal flows were applied to discharge-vs-sediment-retention relations (fig. 11) to obtain an average percent retention for each type of basin (table 8). An annual trap efficiency was then calculated by dividing the total load reported for each seasonal period by the estimated total load retained during that period. The resulting value was then applied to the annual load reported by Kappel and others (1986) to obtain the annual load retained in each type of basin (table 9). The estimated seasonal load and retention for both types of basins at each site are summarized in table 8; the estimated annual load and the expected range of retention based on different particle-size distributions are given in table 9.

Applying individual estimates of seasonal retention to obtain an annual retention weights the annual loads retained by the trap efficiency for the season in which most of the annual load occurs. Approximately half the annual sediment load is transported during the snowmelt period; therefore, the estimated annual retention of suspended sediment is weighted heavily toward this period.

In general, the maximum-storage basins retained more sediment than temporary-storage basins; the estimated annual retention by maximum-storage basins was 75 percent greater at the Thornell site, 41 percent greater at the Linden site, and 18 percent greater at the Allen site. Retention in the maximum-storage basin at the Blossom site was only 13 percent greater than in the quarry because most of the storage capacity is within the quarry.

Table 9.--Estimated annual retention of suspended-sediment loads by flow-attenuation basins.

[Numbers in parentheses represent range of trap efficiency based on retention estimated for the particle-size distribution range.]

Site	Annual load[1] (tons)	Temporary-storage basin: Estimated retention[2] (percent)	Temporary-storage basin: Load retained (tons)	Maximum-storage basin: Estimated retention (percent)	Maximum-storage basin: Load retained (tons)
Thornell	3,800	32 (21-53)	1,200	56 (52-80)	2,100
Linden	6,400	34 (23-46)	2,200	48 (38-61)	3,100
Allen	2,400	28 (19-37)	670	33 (24-41)	790
Blossom[3]	16,000	53 (39-67)	8,500	60 (46-73)	9,600

[1] Annual suspended sediment loads reported by Kappel and others (1986).
[2] Estimated trap efficiency obtained from table 8.
[3] Temporary-storage site refers to the quarry.

Basin Sedimentation

As flow-attenuation basins gradually fill with sediment, they lose storage capacity and thus become less effective. The rate of filling will depend on the rate and particle-size distribution of incoming sediments, the trap efficiency of the basin over time, and compaction or consolidation of sediments retained in the basin.

The calculated density of sediments retained in maximum-storage basins and temporary-storage basins, and of bedload retained in maximum-storage basins, is given in table 10. Estimated density of sediment averaged 64 lb/ft^3 in temporary-storage basins and 58 lb/ft^3 in maximum-storage basins. Sediment that settles in temporary-storage basins has a higher density than that in maximum-storage basins as a result of repeated exposure and drying. Bedload has a greater density due to the predominance of the larger particle-size fraction. The volume of trapped sediment in either type of basin will also decrease somewhat with time through compaction beneath the weight of overlying sediments (Lara and Pemberton, 1963).

Table 10.--Calculated density of bedload and suspended sediment retained in temporary- and maximum-storage basins, by particle-size fraction.

[Density values are in pounds per cubic foot. Site locations are shown in fig. 1.]

Site	Temporary-storage basin			Maximum-storage basin			
	Mean [1]	High clay [2]	High sand [3]	Mean	High clay [1]	High sand [2]	Bedload [3]
Thornell	64	53	68	59	44	64	97
Linden	63	57	70	57	49	66	97
Allen	61	58	63	54	50	57	97
Blossom	67	61	76	62	53	73	97

[1] Based on discharge-weighted mean particle-size distribution.
[2] Based on maximum clay and minimum sand distribution.
[3] Based on maximum sand and minimum clay distribution.

The calculated density values in table 10 were applied to the annual suspended-sediment loads (table 9) and annual bedload to obtain the approximate volume that these sediments would occupy in each type of basin. Annual volumes of suspended sediment retained by each type of basin for the mean and range of particle-size distributions and volume of bedloads are summarized in table 11. Because sand sediments have a greater density than clay sediments, the predominance of sand-size particles does not give greater volume.

Maximum-storage basins retain greater volumes of suspended sediments than temporary-storage basins and also retain material transported along the streambed. The estimated annual volumes of sediments retained in both types of basins at each site are summarized as a percentage of the initial available storage in table 12. The percentages ranged from 0.2 in the temporary-storage basins at Thornell to 0.8 in the maximum-storage basin at Linden but did not change appreciably with changes in particle-size distribution.

Calculations of sediment volume retained show that maximum-storage basins fill with sediment approximately twice as fast as temporary-storage basins. Maximum-storage basins would lose 10 percent of their available storage in 13 to 30 years, whereas temporary-storage basins would lose the same percentage in 23 to 50 years. Loss of storage is a matter of concern in basin management because it reduces trap efficiency.

Table 11.--Annual sediment load and volume retained in temporary- and maximum-storage basins.

[Loads are in tons; volumes are in thousands of cubic feet. Sites are shown in fig. 1.]

A. SUSPENDED-SEDIMENT

Site	Temporary-storage basin			Maximum-storage basin		
	Load retained	Volume		Load retained	Volume	
		Mean[1]	Range[2]		Mean[1]	Range[2]
Thornell	1,200	38	30 - 62	2,100	71	89 - 94
Linden	2,200	70	52 - 85	3,100	110	100 - 120
Allen	670	22	16 - 23	790	29	23 - 34
Blossom[3]	8,500	250	220 - 280	9,600	310	280 - 330

B. BEDLOAD

Site	Load retained	Volume
Thornell	190	4
Linden	320	7
Allen	120	2
Blossom	3,200	66

[1] Calculated from discharge-weighted mean particle-size distribution.
[2] Minimum represents maximum clay content; maximum represents maximum sand content.
[3] Temporary-storage site refers to the quarry.

Table 12.--Annual volume of total sediment retained in basins, as a percentage of initial basin volume.

[Volumes are in thousands of cubic feet. Site locations are shown in fig. 1.]

Site	Initial basin volume	Temporary-storage basin		Maximum-storage basins	
		Average annual volume of sediment retained	Percentage of initial basin volume	Average annual volume of sediment retained	Percentage of initial basin volume
Thornell	19,000	38	0.2	71	0.4
Linden	16,000	70	0.4	110	0.7
Allen	5,800	22	0.4	29	0.5
Blossom[1]	120,000	250	0.2	310	0.3

[1] Temporary-storage site refers to the quarry.

Comparison of Model Results With Those Obtained By Other Methods

The sediment-retention values obtained through simulations are the basis for estimating (1) the decrease in concentrations of chemical constituents, and (2) the useful life or maintenance requirements of the basins. The predicted trap efficiencies are compared with those obtained from empirical relationships and probabilistic determinations reported by others because of their importance and the number of variables that affect them.

Maximum-Storage Basins

Brune curve.--One of the standard predictors of sediment-trap efficiency is the Brune curve, developed in 1953 from empirical relations of 44 reservoirs ranging in size from small farm ponds to major dams (Brune, 1953). The Brune curve expresses trap efficiency as a function of a reservoir's ratio of capacity to inflow, which also is an expression of average retention time. The original curve developed by Brune and an updated curve developed by Heinemann (1981) for small reservoirs is shown in figure 12 along with the sediment-trap efficiencies estimated in this study. The capacity-to-inflow ratio was

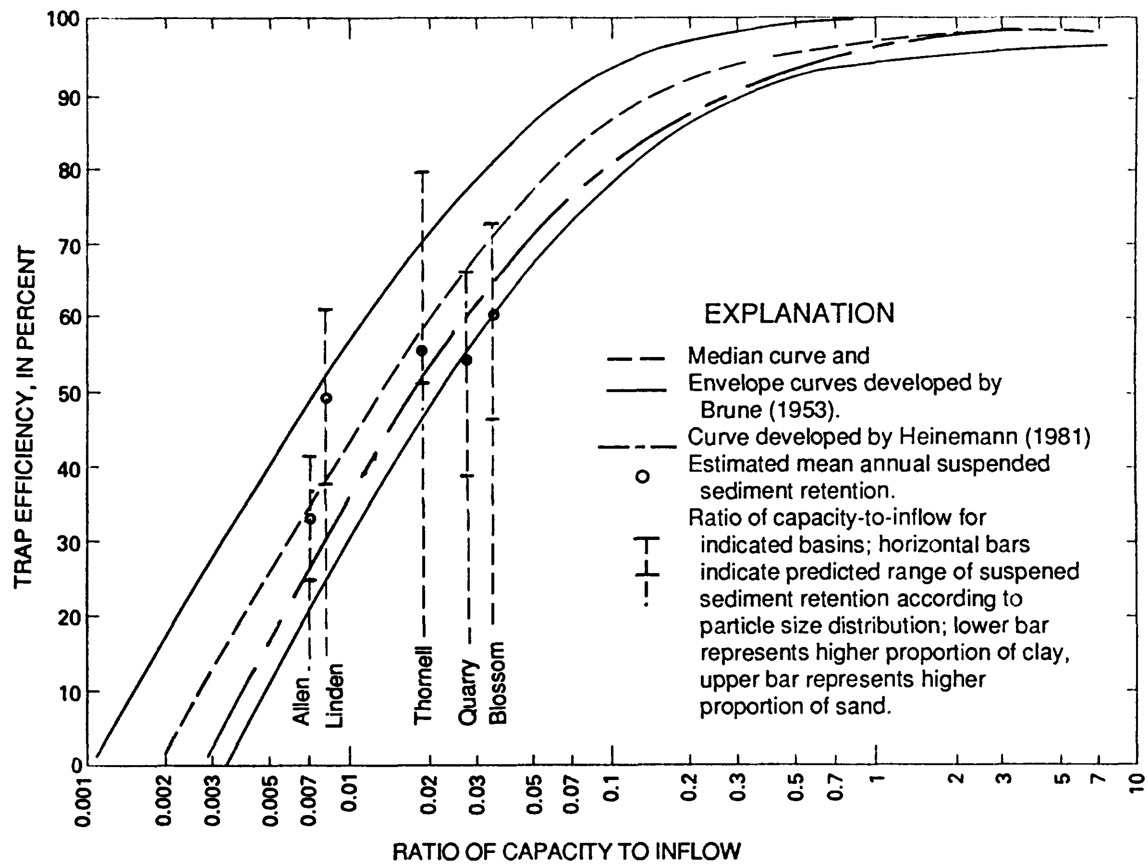

Figure 12.--Simulated trap-efficiency curves of maximum-storage basins (including the quarry at the Blossom site) compared with the curves of Brune (1953) and Heinemann (1981) for normally pooled reservoirs. (Modified from Brune, 1953; Heinemann, 1981.)

calculated from the basin capacity at the point of zero flow, in ft^3, divided by the mean annual discharge, in ft^3. The model-generated trap efficiencies for maximum-storage basins at the Thornell, Linden, and Allen sites, based on the average particle-size distributions, agree closely with those of the original Brune curve, but that for the Blossom site more closely matches the curve reported by Heinemann (1981). This may be an invalid application of the curve, however, because Heinemann's curve was developed for reservoirs with drainage areas less than 15 mi^2, whereas the drainage area at the Blossom site is 143 mi^2. Conversely, the model simulation may have underpredicted sediment retention at Blossom because the quarry has greater depths through which particles must fall to be considered trapped. If so, the performance of the Blossom site may be better represented by the original Brune curve.

Churchill curve.--Although the Brune curve matches the predicted values closely, it does not represent flow dynamics within the reservoir nor differences in particle-size distribution of the sediment. A similar curve developed by Churchill (1948) is considered more descriptive of sedimentation in reservoirs because it takes into account the average velocity through a normally pooled reservoir, provided the flow velocity through the reservoir is known. This value generally is not readily available, however. The Churchill curve indicates the percentage of sediment passing through the reservoir on the basis of a sedimentation index that represents the ratio of average retention time to average flow velocity.

Churchill developed a second curve to account for differences in particle-size distribution of inflows that had previously passed through one or more reservoirs upstream on the assumption that larger particles are removed by the upstream reservoir while finer particles pass through. The Churchill trap efficiency curve, refined by Bube and Trimble (1986), indicates a greater trap efficiency than the model predictions, possibly because the estimates of average velocity through the reservoir, which are based on the approximate length along the center line of the reservoir divided by the average retention time, are crude. The Churchill curve also provides an indication of the effect of upstream flow-attenuation basins on the performance of downstream basins; results suggest that the increase in the proportion of finer particle sizes transported to downstream reservoirs will reduce their performance by 10 to 30 percent.

U.S. Environmental Protection Agency Method.--The U.S. Environmental Protection Agency, as part of the NURP program, developed a probabilistic method for assessing the performance of normally pooled (maximum-storage) basins (U.S. Environmental Protection Agency, 1986). This method, which can use precipitation statistics where streamflow data are lacking, uses more simplifying assumptions than a deterministic approach and therefore may be less accurate. The probabilistic method, when used with measured runoff and precipitation data from individual storms in this study, indicated less suspended-sediment removal than the model, but most results were within the predicted range for fine particle sizes.

Temporary Storage Basins

Trap-efficiency data on temporary storage basins are limited, and this type of basin inherently has a wider variety of configurations than normally pooled basins, which makes general comparison difficult. Brune (1953) indicated the trap efficiency of temporary-storage basins to be significantly lower than that of normally pooled basins with a similar capacity-to-inflow ratio. The limited data used by Brune suggest that temporary-storage-basin trap efficiencies may be at least 30 percent lower than those of normally pooled reservoirs, depending on the capacity-to-inflow ratio. This is consistent with results of this study. An investigation of three small residential watersheds with detention ponds of similar size (Randall, 1982) reported that sediment retention in a dry basin was equivalent to that in the normally pooled basins.

Rausch and Heinemann (1975), who also report lower trap efficiency for temporary-storage basins, showed detention time to be one of the most significant predictors of trap efficiency and that reduced detention time in temporary-storage basins therefore decreases trap efficiency. Further, they noted that elimination of "dead" storage (the pool of water maintained in a maximum-storage basin) permits discharge of the denser sediment and nutrient-enriched water, which tend to accumulate in the bottom of the basin. Hence, temporary-storage basins may be more desirable for maintaining a specified quality of water in the reservoir but less effective for meeting downstream water-quality objectives.

Decrease In Phosphorous, Lead, and Zinc Loads

The proportion of total-chemical to suspended-chemical concentrations in the adjacent Genesee River basin indicates the estimated decrease in the annual suspended (particulate) load in flow-attenuation basins to range from 26 to 65 percent for phosphorus, 28 to 64 percent for lead, and 26 to 61 percent for zinc (table 13). Part of the load of each constituent is in the dissolved phase (and consequently not retained); therefore, the decrease in total annual load amounts to 22 to 59 percent for phosphorus, 20 to 47 percent for lead, and 16 to 38 percent for zinc. Because the estimates of annual suspended-sediment-load retention were weighted heavily toward the snowmelt period, the retention of particulate phosphorus and metals was weighted heavily also.

Maximum-storage basins provide a greater retention of chemical loads than temporary-storage basins because their sediment-trap efficiency is greater. The average retention of total phosphorus, lead, and zinc was 24, 22, and 19 percent, respectively, in temporary-storage basins and 46, 40, and 32 percent, respectively, in maximum-storage basins. Thus, an average maximum-storage basin would provide about 80 percent greater retention of each constituent than a temporary-storage basin.

Basin retention of phosphorus and metals as reported in the literature varies greatly. In general, other studies have shown comparable phosphorus retention but greater metals retention than those predicted in this study.

Calculated retention of total phosphorus in maximum-storage type basins in nine NURP studies ranged from a negative value to 79 percent removal (Athayde and others, 1983); the range reported from other studies ranged from 25 percent for a small pond in Idaho with a capacity-to-inflow ratio of 0.0006 (Brown and others, 1981) to 75 percent at the Callahan Reservoir in Missouri with a capacity-to-inflow ratio of 0.327 (Rausch and Schreiber, 1981). The 29- to 59-percent decrease in total phosphorus predicted for the Irondequoit sites seems consistent with these findings in terms of their capacity-to-inflow ratios.

Metals retention in maximum-storage basins in the NURP studies ranged between 9 and 95 percent for total lead and from 5 to 71 percent for total zinc (Athayde and others, 1983). A study of Lake Ellyn in Illinois reported 91- to 95-percent retention of suspended solids, 84 to 92 percent for total lead, and 76 to 88 percent for total zinc (Striegl and Cowan, 1987). The high correlation between total-metal and suspended-solids retention in the Illinois study supports the assumption used in this analysis that metals are evenly distributed over the range of sediment-particle sizes and are removed in the same proportion as sediment. Settling tests of runoff from urban watersheds in New Jersey (Whipple and Hunter, 1981) and in Washington, D.C. (Randall and others, 1982) reported an average retention of 60 to 86 percent for total lead and 17 to 44 percent for total zinc under ideal conditions.

Table 13.--Annual retention of total and particulate phosphorus, lead, and zinc, August 1980 through August 1981.

[Site locations are shown in fig. 1.]

Constituent	Temporary-storage basin: Particulate retention (percent)	Temporary-storage basin: Total retention (percent)	Temporary-storage basin: Particulate load retained (pounds)	Maximum-storage basin: Particulate retention (percent)	Maximum-storage basin: Total retention (percent)	Maximum-storage basin: Particulate load retained (pounds)
			THORNELL			
Phosphorus	31	25	1,900	60	48	3,600
Lead	28	20	110	64	47	260
Zinc	33	21	6,800	58	36	12,000
			LINDEN			
Phosphorus	32	23	4,000	53	38	6,500
Lead	34	25	400	56	41	650
Zinc	34	21	18,000	52	32	28,000
			ALLEN			
Phosphorus	26	22	1,700	35	29	2,300
Lead	28	21	540	33	24	640
Zinc	26	16	5,400	32	20	6,800
			BLOSSOM[1]			
Phosphorus	60	54	19,000	65	59	20,000
Lead	56	41	2,500	62	45	2,800
Zinc	56	35	53,000	61	38	60,000

[1] Temporary-storage site refers to the quarry.

Remobilization Processes

The remobilization of phosphorus and metals from sediments trapped in a flow-attenuation basin can occur through mechanical resuspension, chemical reactions, and biological activity. The resuspension process depends on flow rate, size and shape of the basin, and the outlet configuration. Temporary-storage basins, which allow normal flow to resume after a storm, will likely resuspend a greater amount of sediment and associated chemical constituents than maximum-storage basins. Chemical reduction reactions occur under low-pH and low dissolved-oxygen conditions and release phosphorus and metals associated with the sediments as more soluble forms.

Phosphorus will migrate from deep anaerobic sediments to the interface between sediment and water. If the overlying water and the sediment surface are both aerobic, some phosphate may be released, but most is retained in the aerobic upper layer through formation of ferric complexes (Fillos and Swanson, 1975). This aerobic sediment layer is generally not more than about 1/10 inch deep. When the overlying water becomes anaerobic, the ferric complexes break down, and phosphates are released. Gachter (1976) found that sediments act as a phosphorus source when the dissolved oxygen concentration of the water is below 1 mg/L and as a phosphorus sink when oxygen concentrations exceed 3 mg/L. Under constant or intermittent anaerobic conditions, the rate of phosphorus release from the sediment may be sufficient to keep water in a eutrophic state long after external sources of phosphorus have been eliminated (Fillos and Swanson, 1975).

Irondequoit Creek and its main tributaries are at or near saturation with respect to dissolved oxygen throughout the year (L. P. Spittle, Monroe County Environmental Health Laboratory, written commun., 1987). Therefore, flow-attenuation basins will probably remain aerobic throughout the year and inhibit remobilization of phosphorus from the sediments. The possible exception would be the quarry at the Blossom site, where prolonged winter and summer stagnation in the deep area could cause brief anaerobic conditions that could release phosphorus.

Depletion of dissolved oxygen near the sediment-and-water interface also will cause the release of metals into the dissolved phase. Striegl and Cowan (1987) report a reduction of 84 to 92 percent of total lead but an increase of 290 to 600 percent of dissolved lead at Lake Ellyn, Ill., by remobilization of particulate lead into the dissolved phase. Water near the bottom of Lake Ellyn has been reported to become anaerobic during periods of summer stagnation (Hey and Schaefer, 1983).

Metal desorption and solubility generally increase with decreasing pH. The average pH values of streams in the Irondequoit Creek basin ranged from 8.3 during the summer to 7.5 in the fall (U.S. Geological Survey, unpublished data on file in Ithaca, N.Y., 1981). Although the pH of the bottom water in the maximum-storage basins may differ somewhat from these values, the pH of water in the Irondequoit Creek basin does not appear to be low enough to materially affect sorbtion rates or the solubility of metals.

In addition to the effects of pH and dissolved oxygen, chloride from road-deicing salts and other sources can cause mobilization of metals by forming soluble chloro complexes (Hey and Schaefer, 1983). This may be a major factor in the Irondequoit Creek basin, which receives large amounts of deicing salts (Kappel and others, 1986; Diment and others, 1974) and a high percentage of the annual lead and zinc load during the snowmelt and spring runoff periods, when chloride levels are highest.

Predicted Decrease In Loads To Irondequoit Bay

Simulations indicate that the four flow-attenuation basins would individually and collectively decrease the loads of suspended sediment and associated chemical constituents that enter Irondequoit Bay. Individually, each basin would reduce the load entering Irondequoit Bay by the amount estimated for that basin if channel erosion downstream of the basin and resuspension were minimal. Some streams undergo rapid downstream erosion when sediment-laden water is replaced by clear water from a reservoir, however (Komura and Simmons, 1967; Petts, 1977; Morisawa, 1985). If this occurs, not only could the stream morphology change below the basin (Williams and Wolman, 1985), but the effectiveness of the basins would diminish as new sediments and associated chemical constituents are entrained.

A mass-balance approach was used to estimate the combined effect of flow-attenuation basins. The loads entering the Linden basin consist of the load discharged from the Thornell basin plus the load derived from the intervening area between basins; therefore, the load derived from the intervening area was added to the load from the Thornell site to adjust the inflow loads to this basin. The load entering the Blossom basin was adjusted in a similar fashion for upstream retention at the Linden and Allen basins.

The performance of the two downstream basins would probably be affected by the decrease in the sediment-particle size at the upstream basins. Model simulations showed decreases of 20 to 30 percent in trap efficiency in response to decreases in particle size. Trap efficiencies of reservoirs studied by Churchill (1948) were reduced by 10 to 30 percent in such instances. The trap efficiency of the Linden and Blossom basins would probably decrease because the Thornell and Allen basins would discharge an increased proportion of fine sediment. To account for this, only the retention values obtained for fine-grained sediments at the Linden and Blossom sites were applied to the adjusted load entering the basin to obtain the total annual reduction in loadings to Irondequoit Bay from all four basins.

If trap efficiencies were shifted in this manner, annual suspended-sediment loads from the Linden site decreased by an additional 5 percent in the temporary-storage basin and 22 percent in the maximum-storage basin. The annual loads at the Blossom site, adjusted for the Linden and Allen basins upstream, increased 7 percent in the quarry and decreased 3 percent in the maximum-storage basin.

The degree to which peak flows are delayed, and the magnitude of peak-flow reductions, will also influence the performance of downstream flow-attenuation basins. The effects of flow attenuation will be additive; thus, the more flow is regulated upstream, the more it can be regulated downstream to further decrease peaks and prolong recessions. Alternative control designs, such as drop-inlet structures or undersized culverts, which maximize the available storage by emptying the basins between storms and cause a greater change in stage for a given change in discharge, would minimize flow attenuation.

A reduced peak discharge and prolonged recession would increase sediment retention in downstream basins but probably not by more than the amount predicted from the mean particle-size distribution. If so, the annual reduction would be expected to increase 23 percent in the temporary-storage basin and 49 percent in the maximum-storage basin at the Linden site, 23 percent at the quarry, and 39 percent in the maximum-storage basin at the Blossom site. The retention of suspended sediment and associated chemical constituents would likely be somewhere between these values. The predicted decreases in suspended sediment, total phosphorus, total lead, and total zinc loads into Irondequoit Bay from individual and combined basins are summarized in table 14.

Although the reduction of peak flows in a series of flow-attenuation basins is usually additive, some exceptions may be expected. Detention storage can increase peak discharge rates if the delayed arrival of the peak discharge coincides with peak runoff from contributing drainage areas (Hawley and others, 1981). The effects of this possibility were beyond the scope of this study, however.

Table 14.--Predicted reduction of suspended sediment, total phosphorus, lead, and zinc loads to Irondequoit Bay, August 1980 through August 1981.

[Values are percent of total load. Site locations shown in fig. 1. Data from Kappel and others, 1986.]

	Temporary-storage basins				Maximum-storage basins			
Site	Suspended sediment	Total phosphorus	Total lead	Total zinc	Suspended sediment	Total phosphorus	Total lead	Total zinc
Thornell	6	5	1	4	11	9	4	7
Linden	11	10	6	10	16	16	9	15
Allen	3	4	8	3	4	6	9	4
Blossom	46	46	35	30	51	50	39	32
Combined[1]	43	40	30	26	52	48	38	33
Combined[2]	55	52	42	38	62	58	48	43

[1] Combined reduction for all sites based on reduced trap efficiency at Linden and Blossom sites.
[2] Combined reduction for all sites based on trap efficiency of mean particle size.

Transferability of Model Results

A major problem in applying the results of basin simulations to other sites is the wide range of physical conditions. Some conditions are site specific, such as configuration of the control, shape of the basin, and storage capacity in relation to the contributing drainage area; others, such as magnitude and duration of runoff, particle-size distribution of suspended sediments, and the association of chemical constituents with the suspended sediments, are variable through time. As a result, the retention-efficiency values obtained for the four sites simulated in this study are not readily transferable.

The maximum-storage basins showed fairly consistent patterns of annual retention in relation to the capacity-to-inflow ratio of the basin. If annual discharge data can be obtained by direct measurement or by correlation from nearby sites, the capacity-to-inflow ratio and sediment retention, as described by Brune (1953), would seem to apply reasonably well in the Irondequoit Creek watershed. The probabilistic procedure developed by the U.S. Environmental Protection Agency (1986) for calculating trap efficiency of normally pooled basins from measured runoff characteristics also seems to apply reasonably well to the Irondequoit Creek watershed. This method also can be used with local precipitation statistics in the absence of discharge data, although this was not examined in this study.

The general linear relations between discharge and percent trap efficiency for both types of basins (fig. 13) can be used to estimate suspended-sediment retention for individual stormflows at each site. The regression line shown in figure 13 has a r^2 value of 44 for temporary-storage basins and 68 for maximum-storage basins. The r^2 value is an indication of the amount of variation of the dependent variable (percent trap efficiency) that is explained by the independent variable (discharge, in $[ft^3/s]/mi^2$). The greater variation in sediment retention among temporary-storage basins probably results from the greater variability of storage capacity-vs-outflow relations. The mean stormflow also could be applied to basins of similar capacity or interpolated between sites of similar capacity to obtain a better estimate of suspended-sediment retention.

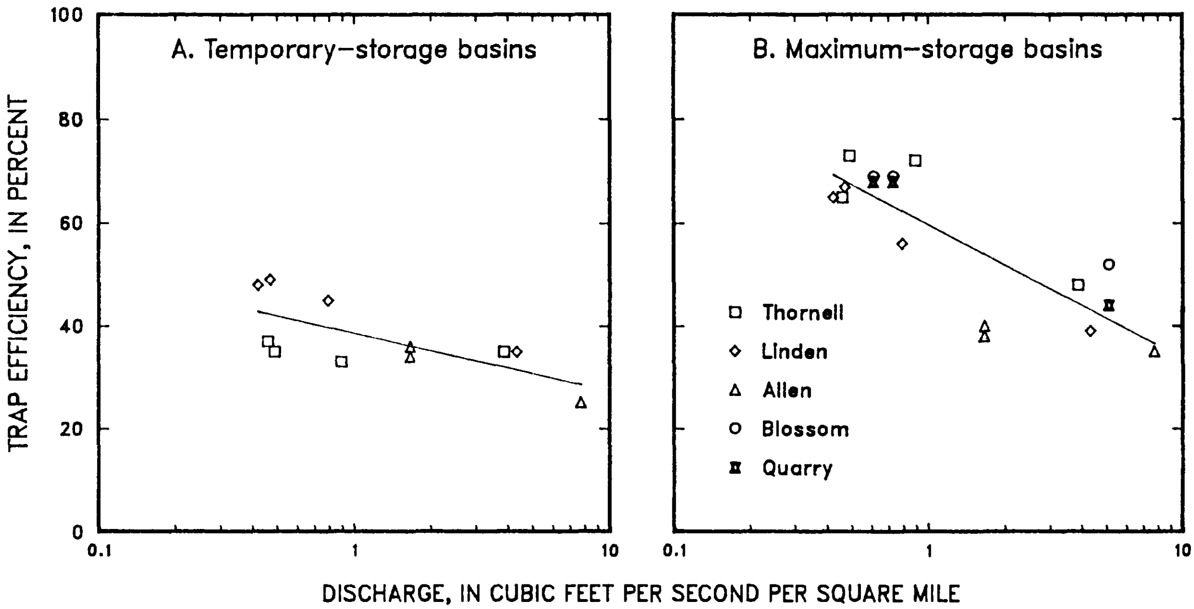

Figure 13.--Relation between stream discharge and percent suspended-sediment retention for mean particle-size distribution in temporary- and maximum-storage basins. (Site locations are shown in fig. 1.)

SUMMARY AND CONCLUSIONS

Simulations of flow-attenuation basins indicate promise for improving chemical quality of nonpoint-source storm runoff. Many variables that affect the performance of such basins were tested, and a wide range of sediment-retention efficiencies were obtained. A deterministic modeling approach was used to predict how such basins would perform over a variety of stormflows observed at four selected sites from the Irondequoit National Urban Runoff Program (NURP). Two types of storage basins were simulated: a temporary-storage type designed to impound storm runoff but allow normal streamflow to pass unimpeded, and a maximum-storage type designed to maintain a permanent pool of water.

Simulations were based on discharge and water-quality data collected in the NURP program from July 1980 through August 1981. Flow and sediment-retention simulations were made for each type of basin at each site for three to four stormflows ranging from moderate discharge with a high frequency of occurrence to a large discharge that occurs only once every 1 to 4 years.

The capacity of the simulated basins to modify flow depended on the ratio of storage capacity to the contributing drainage area. The decrease in peak flow was greatest for storms with moderate discharge at basins with a high ratio of storage capacity to contributing drainage areas but also was dependent on the configuration of the outlet control. Peak discharge generally was decreased more in temporary-storage basins because they are normally empty and thus have a greater storage capacity.

Retention of suspended sediment varied with particle-size distribution and detention time, which in turn are a function of discharge, storage capacity, and type of control structure. Simulations of three particle-size distributions (predominantly sand, predominantly clay, and intermediate) at each site showed significant differences in retention efficiency. In both types of basins, retention of average particle-size sediments was 20 to 30 percent less than that for sediments with a high proportion of sand-size particles and 20 to 30 percent greater than that for sediments with a high proportion of clay-size particles.

Detention time averaged 23 hours in maximum-storage basins and about 1.3 hours in temporary-storage basins, which accounts for the generally greater retention efficiency of the maximum storage basins. The retention of suspended sediment during individual storms in maximum-storage basins exceeded that in temporary-storage basins by 84 percent at the Thornell site, 28 percent at the Linden site, and 8 percent at the Allen site. At the Blossom site the maximum-storage basin averaged 6 percent greater retention than the quarry. The estimated retention in terms of percent annual suspended-sediment loads at the Thornell, Linden, Allen, and Blossom sites, respectively, was 32, 34, 28, and 53 percent in temporary-storage basins and 56, 48, 33, and 60 percent in maximum-storage basins.

Maximum-storage basins retained bedload (estimated as a percentage of the suspended-sediment load) in addition to suspended sediment. The control configuration in temporary-storage basins was assumed to allow only negligible bedload retention. In maximum-storage basins, however, the retention of bedload and suspended sediment caused more rapid sedimentation (decrease in storage capacity), which would amount to about a 10-percent decrease in storage capacity in 13 to 30 years, whereas an equivalent loss of storage in a temporary-storage basin would take 23 to 50 years.

Decreases in particulate phosphorus, lead, and zinc loads varied with sediment retention because these were assumed to be retained in equal proportions and evenly distributed among the three particle-size categories. The average retention of particulate phosphorus, lead, and zinc in the temporary-storage basins was 24, 22, and 19 percent; that in maximum-storage basins was 46, 40, and 32 percent. The average retention of these constituents was about 80 percent greater in maximum-storage basins than in temporary-storage basins because they retain more sediment.

Remobilization of phosphorus and metals may result from physical resuspension of sediments within the basin and conversion of constituents into more soluble forms under reducing (anaerobic) conditions. Metals also may be mobilized through the formation of soluble chloro complexes from road-deicing salts. These processes may considerably reduce the total retention of these constituents.

The overall effect of flow-attenuation basins on loads entering Irondequoit Bay will depend on the number of sites and type of controls used, in addition to stormflow characteristics and other factors. Upstream flow-attenuation basins may decrease the performance of downstream basins by increasing the proportion of finer suspended-sediment particles, but this may be offset by the increased capacity of the stream to entrain new sediment. The process of deposition in basins and erosion downstream may cause changes in stream morphology.

In terms of total load entering Irondequoit Bay through the Irondequoit watershed, the estimated decrease ranges from 43 to 55 percent for suspended sediment, 40 to 52 percent for total phosphorus, 30 to 42 percent for lead, and 26 to 38 percent for zinc in temporary-storage basins, and from 52 to 62 percent for suspended sediment, 48 to 58 percent for phosphorus, 38 to 48 percent for lead, and 33 to 43 percent for zinc in maximum-storage basins.

Results of this analysis indicates that both types of basins may greatly improve the quality of water entering Irondequoit Bay and that maximum-storage basins would retain greater amounts of sediment and associated chemicals than temporary-storage basins. The effects of flow-attenuation basins are poorly documented, however, and the accuracy of the predictions given here cannot be quantified at present and would require comparison with results of field tests.

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